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# A synoptic climatology of Alaska: Winter 700mb height anomaly patterns and surface climate variability, 1956–1986

Milkovich, Mary F., M.S.

University of Alaska Fairbanks, 1989

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# A SYNOPTIC CLIMATOLOGY OF ALASKA:
Winter 700mb Height Anomaly Patterns
and Surface Climate Variability
1956-1986

A
THESIS

Presented to the Faculty of the University of Alaska
in Partial Fulfillment of the Requirements
for the Degree of

MASTER OF SCIENCE

By
Mary F. Milkovich

Fairbanks, Alaska
September 1989

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A SYNOPTIC CLIMATOLOGY OF ALASKA:
Winter 700mb Height Anomaly Patterns
and Surface Climate Variability
1956-1986

by
Mary F. Milkovich

RECOMMENDED:

Theodore F. Fathauer
T. E. Fathauer

Thomas C. Royer
T. C. Royer

Glenn E Shaw.
G. E. Shaw

H. L. Tanaka

G. Wendler

G. E. Weller, Chairman, Advisory Committee

APPROVED:

K. Jayaweera, Dean, College of Natural Sciences

L. Proenza, Dean of the Graduate School

8/28/89
Date

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**Abstract**

An objective, descriptive study of Alaska's winter season synoptic climatology is compiled to identify regional monthly 700mb anomaly height patterns and to investigate monthly-mean surface temperature and precipitation variability during the thirty-year period from 1956/57 to 1985/86. A total of 78% of the period's monthly 700mb anomaly height maps are classified into ten Basic Anomaly Pattern categories by a Kirchhofer/ Lund-based pattern classification scheme. Patterns are described in terms of frequency of occurrence, climate associations, and specific climate events (case study format). Examination of the winter monthly-mean temperature and precipitation records for the nine NOAA-designated Alaska climate divisions, and the Gulf of Alaska indicates a cool, dry period in the January record from 1964-1977. The winters following 1977 are the most variable of the thirty-year record. Seasonal-scale linear trends indicate a warmer, drier shift in the interior divisions and a warmer, wetter shift in the southern coastal divisions.



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**Acknowledgments**

I would like to thank my graduate advisory committee chaired by Prof. Gunter Weller of the Geophysical Institute, for the lively discussions and enthusiastic support of my interdisciplinary interests. Partial funding for this research was provided through NASA Grants NAGW-932, GSFC 88-1, and NCA 5-112.

I would also like to thank:

My parents for their interest in my success;

Li Yuan and Nettie La Belle-Hamer for sharing their programming and scientific expertise as well as their friendship and patience;

Michele Joly and Dane Patterson for their friendship and encouragement.

Finally, I would like to extend thanks to all of my other friends and colleagues in and out of the academic community for their contributions to the successful completion of this degree.



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# Chapter 1 : INTRODUCTION

The Alaska climate system is an important, but little understood part of the Arctic and in turn, global climate system. As more emphasis (International Geosphere-Biosphere Program, First Global Atmospheric Research Program) is now being placed on global change and the global climate system, it is becoming increasingly apparent how little is known about the Arctic Region's climatology. However, current investigations of climatic variability have indicated that the Arctic and sub-Arctic are the regions with the greatest potential for change. In an effort to respond to this challenge for a more complete understanding of the region's climate behavior, a renewed emphasis is being placed on Alaska and Arctic climate research. One of the first major steps in this renewed Arctic effort is to objectively define Alaska's basic winter climate elements—the surface climatology and the major upper-air circulation features.

The climate of Alaska's winter season is characterized by extremely variable phenomena. The dynamic meteorology of the region is the result of multi-directional feedback loops between atmospheric, land, and ocean components. Current research is primarily focused on the winter season because it is the most dynamically variable season in Alaska, and because climate models indicate that the greatest global change may take place during the arctic winter season.

Previous research (Namias, 1969; Horel, 1981; Wallace and Gutzler, 1981; Dole and Gordon, 1983; Gyakum *et al.*, 1989; Namias *et al.*, 1988) has shown that two of the most prominent atmospheric features directly affecting Alaska's winter climate variability are the somewhat persistent Aleutian Low (Gulf of Alaska), and the Siberian High (interior and northern sectors). The Gulf of Alaska and the entire North Pacific sector are well-noted regions of intense cyclogenesis and storm decay (cyclolysis) (Anderson *et al.*, 1988).



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The components of Alaska's surface climatology play a role equivalent to that of the atmospheric circulation in determining the region's overall climate behavior. The wide range of topography found in Alaska and the actual geographic area covered by the state contribute to a great diversity of localized winter phenomenon. The diversity is further enhanced by the differences in insolation across the region. Alaska is surrounded by three major water bodies— the North Pacific/ Gulf of Alaska, the Bering Sea, and the Arctic Ocean. The latter two are covered with varying concentrations of sea ice throughout much of the winter. Evidence from recent investigations have indicated the presence of sub-region and statewide surface-level climate fluctuations including: a warming in the Gulf of Alaska sea surface temperatures (Royer, personal comm.); a ten-year cycle of statewide warming and cooling, and a near disappearance of ice fog in Fairbanks (Bowling, 1988); and a warming in the arctic/sub-arctic permafrost (Osterkamp, 1987; Lachenbruch *et al.*, 1988; Lachenbruch and Marshall, 1986). Proposed causes of these deviations in the climate range from a shift in the atmospheric circulation to an increase of carbon dioxide in the arctic atmosphere .

The primary purpose of this thesis is to provide a "synoptic climatology" framework describing Alaska's winter season with the premise that it might serve as a foundation for future research.

A "synoptic climatology" study is perhaps the most efficient method of increasing one's knowledge of a particular region's meteorological characteristics. As defined Barry and Perry (1973), a synoptic climatology is "concerned with obtaining insight into local or regional climates by examining the relationships of weather elements, individually, or collectively to atmospheric circulation processes". The synoptic climatology process can also be described as an "analysis of the structure of climate with interest directed to geographical distributions and to practical predictions for different parts of the world " (Sutcliffe, 1964).

In compiling the atmospheric circulation portion of a synoptic climatology, two major types of map pattern classification are commonly used. These are the subjective method and the more objective "computer assisted" (Yarnal, 1984b) (i.e. principal components, cluster analysis, correlation)

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method. While the computer-assisted method is not entirely free from subjectivity, it does have several positive attributes that are not characteristic of the truly subjective method. The computer-assisted process allows: calculation of basic statistics for a set of data; duplication of classification procedures with similar results being obtained by other users; and application of classification output to models for other types of research. The method chosen to create the catalog of winter $700mb$ anomaly patterns presented in this thesis is a computer-assisted classification method based on the techniques introduced by Kirchhofer (Kirchhofer, 1973) and by Lund (1963).

The surface climate portion of a synoptic climatology can take on many forms; but, it is generally based on the quantitative output of mean values, anomaly values, frequencies, and/or persistence patterns. Climate data may be composed a variety of records such as hydrologic records for glacier study (Harrison, 1987; Mayo, pers. comm.; Post and LaChapelle, 1971), surface level meteorological observations for describing local climates (Bowling, 1987; Wise, 1988; Weller and Bowling, 1975) and even geologic landforms in the case of paleoclimatic reconstruction (Hopkins, 1988). Regional-scale monthly mean temperature and precipitation records from Alaska's winter season are examined in this thesis.

The construction of the Alaska winter synoptic climatology begins in Chapter 2 with a review of previous Northern Hemisphere and regional winter synoptic climatology research.

Chapter 3 contains the $700mb$ anomaly pattern catalog as suggested by the first part of Barry's synoptic climatology definition (Barry and Perry, 1973). Month-scale anomaly patterns based on departures from the associated $30yr.(1956 - 1986)$ mean $700mb$ patterns form the basis of the classification process. Although the primary emphasis is placed on monthly-scale anomaly patterns, pentad-scale anomaly patterns are also created for use in investigations of associations between circulation and surface climate.

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A regional, surface-level climatology of Alaska is presented in Chapter 4. Included are monthly mean temperature and precipitation statistics from the nine land-based NOAA Alaska climate divisions. The nine divisions (Fig. 1.1) include the Southeastern, South Coast, Southwestern Islands, Cook Inlet, Copper River, Bristol Bay, West Central, Interior Basin, and the Arctic Drainage. A tenth division, the Gulf of Alaska, is also included to examine the associations between atmosphere and ocean behavior (sea surface temperature).

In Chapter 5, the results of Chapters 2, 3, and 4 are combined to investigate possible associations between the surface climate and the atmospheric circulation. Emphasis is placed on the surface climate associated with each of the basic circulation patterns discussed in Chapter 3. Variations in the regional associations or frequencies of occurrence that might indicate longer term climate fluctuations are examined. Finally, case studies of representative regional cold, warm, normal temperature events, as well as wet, dry, and normal precipitation events are presented.

Chapter 6 contains concluding remarks and suggestions for future research.

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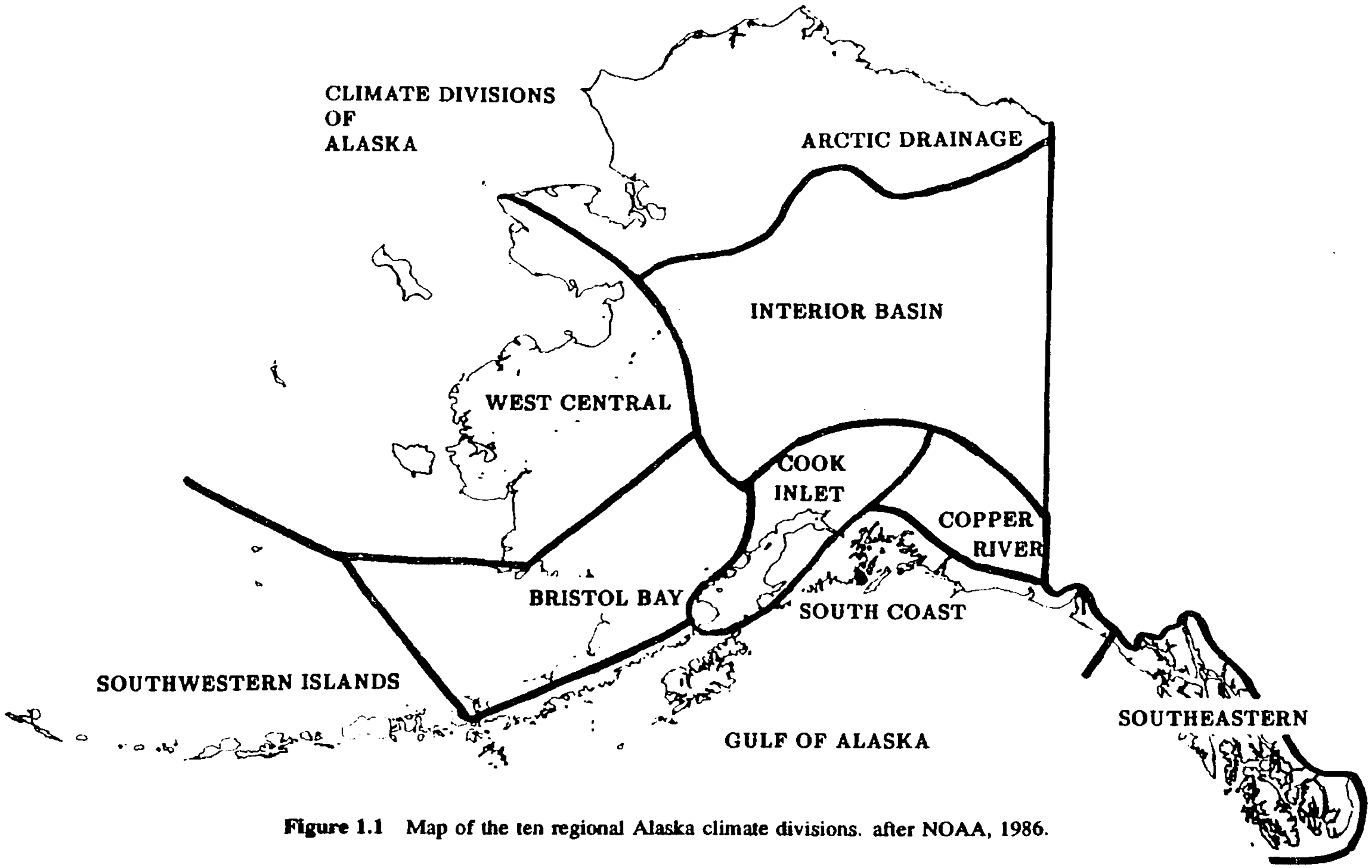


**Figure 1.1** Map of the ten regional Alaska climate divisions. after NOAA, 1986.

## Chapter 2: Background

Before undertaking the actual process of compiling a synoptic climatology of Alaska's winter season, it is necessary to investigate the Arctic/Sub-Arctic region's climatology as it is currently understood in terms of atmospheric circulation and regional surface-level climate. Although several of the studies mentioned cover the entire year, only the winter-oriented results will be discussed as this is to be the focus of this thesis. The background information presented in this chapter provides both a foundation and a means of validation for the results unfolded in later chapters.

### 2.1: Atmospheric Circulation

The mean January arctic circulation (Fig. 2.1) is characterized by a circumpolar westerly vortex (Moritz, 1979; Hare and Hay, 1974) at $500mb$. It is predominantly a three-wave pattern with mid-latitude troughs located at $140°E, 60°W$ and $45°E$. Closed high-latitude lows are found at $65°W$ and $135°E$. With the exception of the Aleutian Chain, Alaska is positioned beneath a ridge. The Asian trough extends over the tip of the Aleutian chain. The $700mb$ mean January circulation shown in figure 2.2 is quite similar to that seen at $500mb$. It, too, is a three-wave pattern with two closed lows centered at $150°E$ and $75°W$. The third wave feature is a less-pronounced trough situated over eastern Europe. The features on the $700mb$ chart are located just downstream from the corresponding features on the $500mb$ chart. At the surface, (Fig. 2.3) the large polar vortex is split into distinct pressure features. A closed low commonly referred to as the Aleutian Low exists at the westward tip of the Aleutian Chain. A strong high pressure system known as the Siberian High dominates Eastern Europe and Asia. A second low, the Icelandic Low, is found east of Greenland. High pressure



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extends across northwest Canada to the Beaufort Sea region, meeting the Siberian High to the north of the broad Aleutian Low.

The mean positions of the troughs and ridges are maintained by a combination of surface topography through conservation of potential vorticity and atmosphere-ocean thermal contrasts (Palmen and Newton, 1969). The major troughs are located downstream of major mountain ranges. Secondly, the troughs are located in the vicinity of warm ocean currents —Gulf Stream or Kuroshio— where the large atmosphere/ocean temperature contrast contributes to long-term instability.

Discussion will now focus on specific shorter-period Northern Hemisphere winter patterns as determined by subjective and objective statistical means. A study by Barnston and Livezey (1987) has applied the rotated principal component analysis technique to monthly mean data and $10-day$ mean data composed of $700mb$ geopotential heights. A total of 35 years of data covering the period from 1954-1980 were included. This work defined several major monthly-scale anomaly patterns. Four of these are dominant winter patterns that might directly influence Alaska's climate. They are the Pacific/North American (PNA), the East Pacific (EP), the Northern Asia (NA), and the West Pacific Oscillation (WPO). In figures 2.4-2.7, the patterns are presented in anomaly form based on eigenmodes of the principal component analyses. The eigenvectors have been computed from a correlation matrix that was based on time variations of 700mb gridpoint values. These eigenvectors have been rotated or linearly transformed (varimax rotation) to produce circulation patterns. The percentage figure shown in each of the figures is the percent of "total variance explained by the principal component for one month averages" (Barnston and Livezey, 1987) of 700mb heights. The mode number in the figures is the principal component used to create the figure. Patterns can be interpreted similarly to teleconnections. When available, complete winter season time series of the patterns are shown to depict the seasonal progresion of the main features in the patterns.

The Pacific North American (PNA) pattern, shown in Fig. 2.4, is found throughout the year in the Northern Hemisphere although it is thought to be most dynamic in the winter months (Namias,

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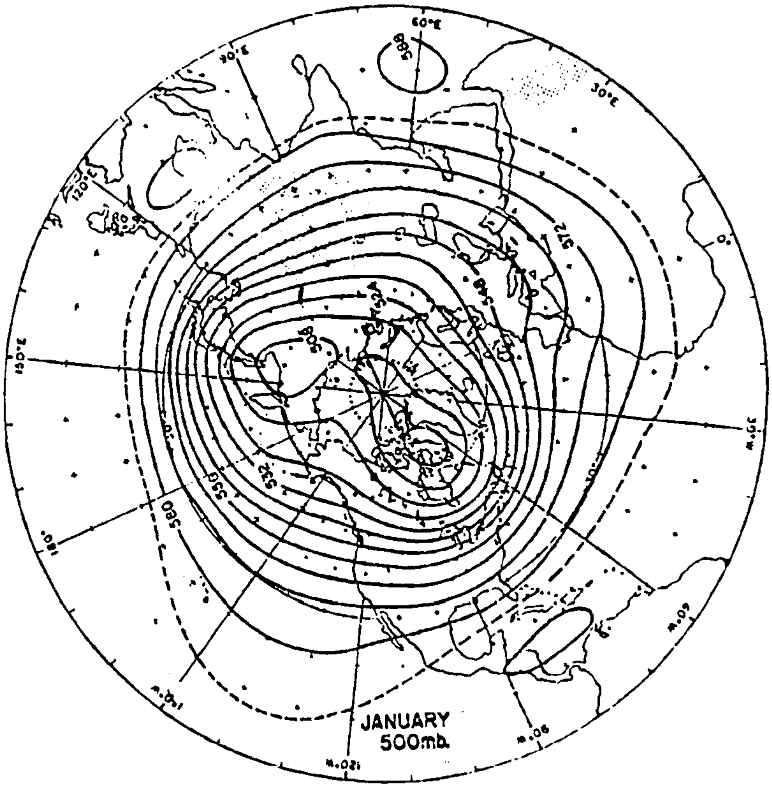


**Figure 2.1** Mean 500mb heights-North Hemisphere January. Contours are 80m (Wilson, 1967).

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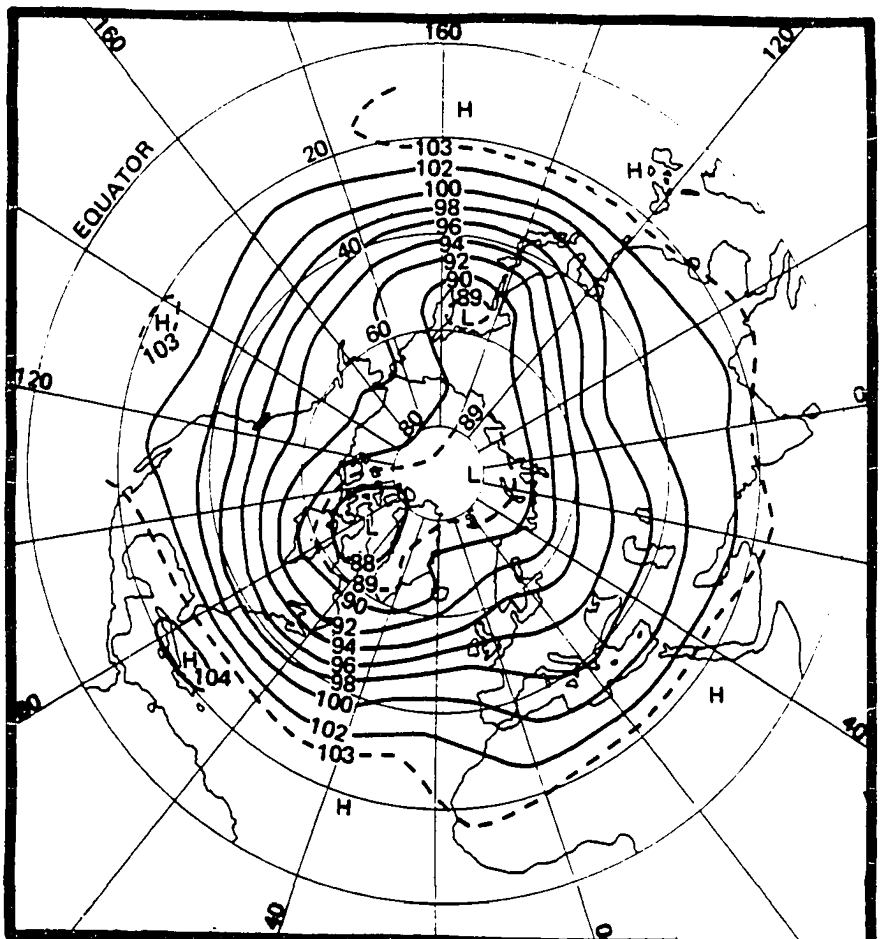


**Figure 2.2** Mean 700mb heights-North Hemisphere January. Contours are 100ft(30m); (Barry and Chorley, 1987).

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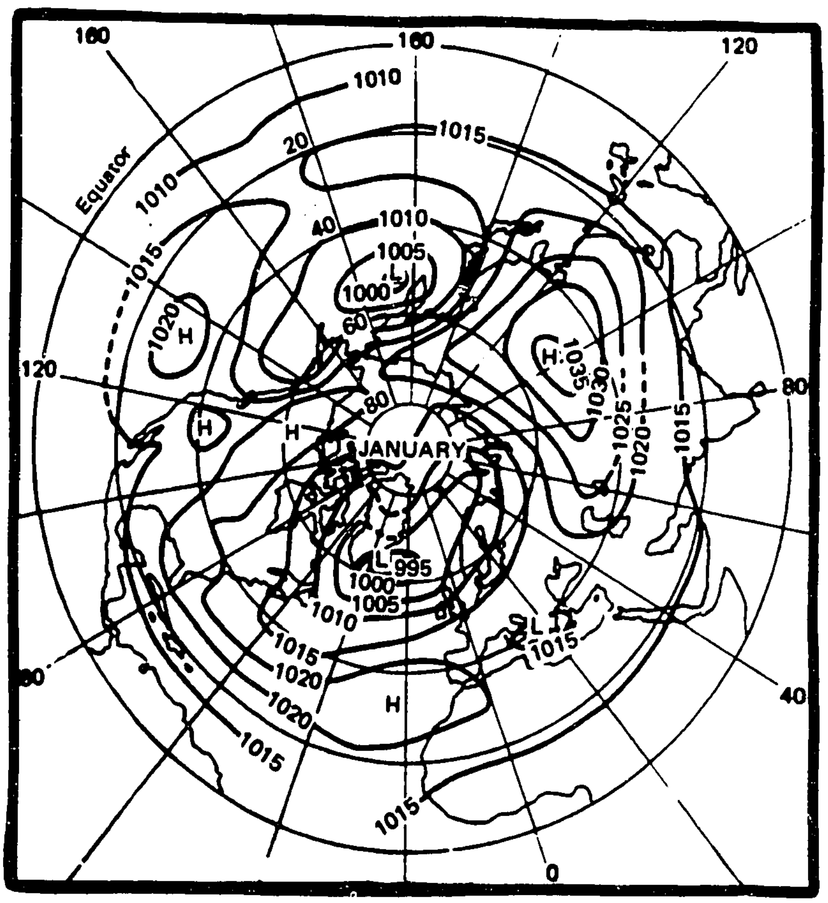


**Figure 2.3** Mean sea level pressure-North Hemisphere January. Contours are 5mb (Barry and Chorley, 1987).

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1978; Namias and Cayan, 1981). During PNA winters, the statistical Aleutian low is much more intense than in non-PNA winters (Wallace and Gutzler, 1981; Namias and Cayan, 1981; Niebauer, 1988). The pattern has also been associated with many of the strong El-Nino/Southern Oscillation (ENSO) episodes over the last thirty years (Namias *et al.*, 1988; Niebauer, 1988).

During the winter season, the pattern has two similarly-signed strong centers, separated by a third center of opposite sign. The two similar-signed centers are generally depicted as negative anomalies (Horel, 1985; Wallace and Gutzler, 1981; Dole, 1986) and the third center is positive as shown. The first negative center is located near $170°W$ in mid-winter and near $150-160°W$ during the rest of the season (Barnston and Livezey, 1987). Latitude range is between $40°N$ and $50°N$. The second negative center is positioned over the Southeastern United States. The positive anomaly feature is set along the Rocky Mountains and the U.S./Canadian border, between the two negative systems. Its center is near $105-125°W$, $50°N$. Referring to the pattern evolution shown in Fig. 2.4, the PNA pattern appears to attain its maximum winter intensity in February.

This pattern's existence and prominence is well-supported by the work of Hsu and Wallace, (1985); Horel, (1985); Wallace and Gutzler, (1981); Namias, (1975); Dole and Gordon, (1983); and many others.

The East Pacific (EP) pattern (Fig. 2.5) of Barnston and Livezey (BL) (1987) is the weakest pattern of the four in terms of the principal component analysis. However, it is of some importance to Alaska as one of its two strong centers is located directly over the state. This feature runs from $180°E$ to $95°W$. Its north/south extent is $80°N$ to $50°N$. To the south of this positive feature is a tight gradient leading to an almost equally intense oppositely-signed feature. The pattern is essentially a north-south dipole set along the west coast of North America. This pattern also appears in the Northern Hemispheric winter circulation study undertaken by Horel (Horel, 1981).

The third pattern described by BL (1987) is the Northern Asia (NA) pattern (Fig. 2.6). This is one of the most arctic-oriented patterns found in BL's results. The pattern is similar to the Siberian

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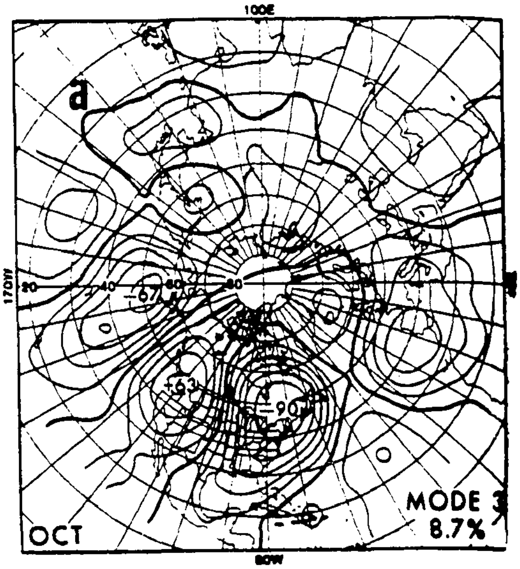


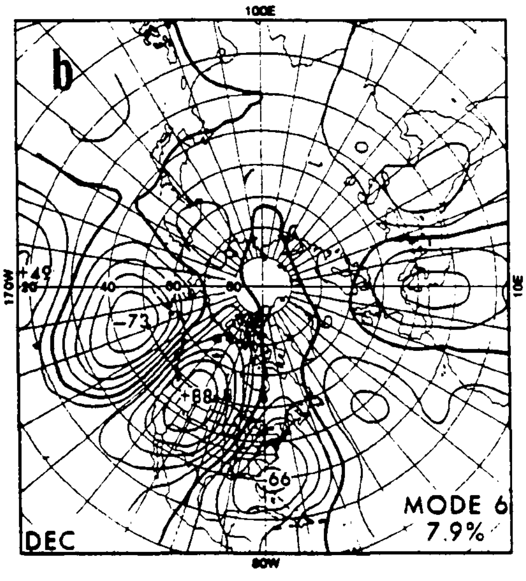


**Figure 2.4** The Pacific North American pattern-700mb anomaly. (a) October and (b) December structure (Barnston and Livezey, 1987); see text for explanation of modes and percentages.

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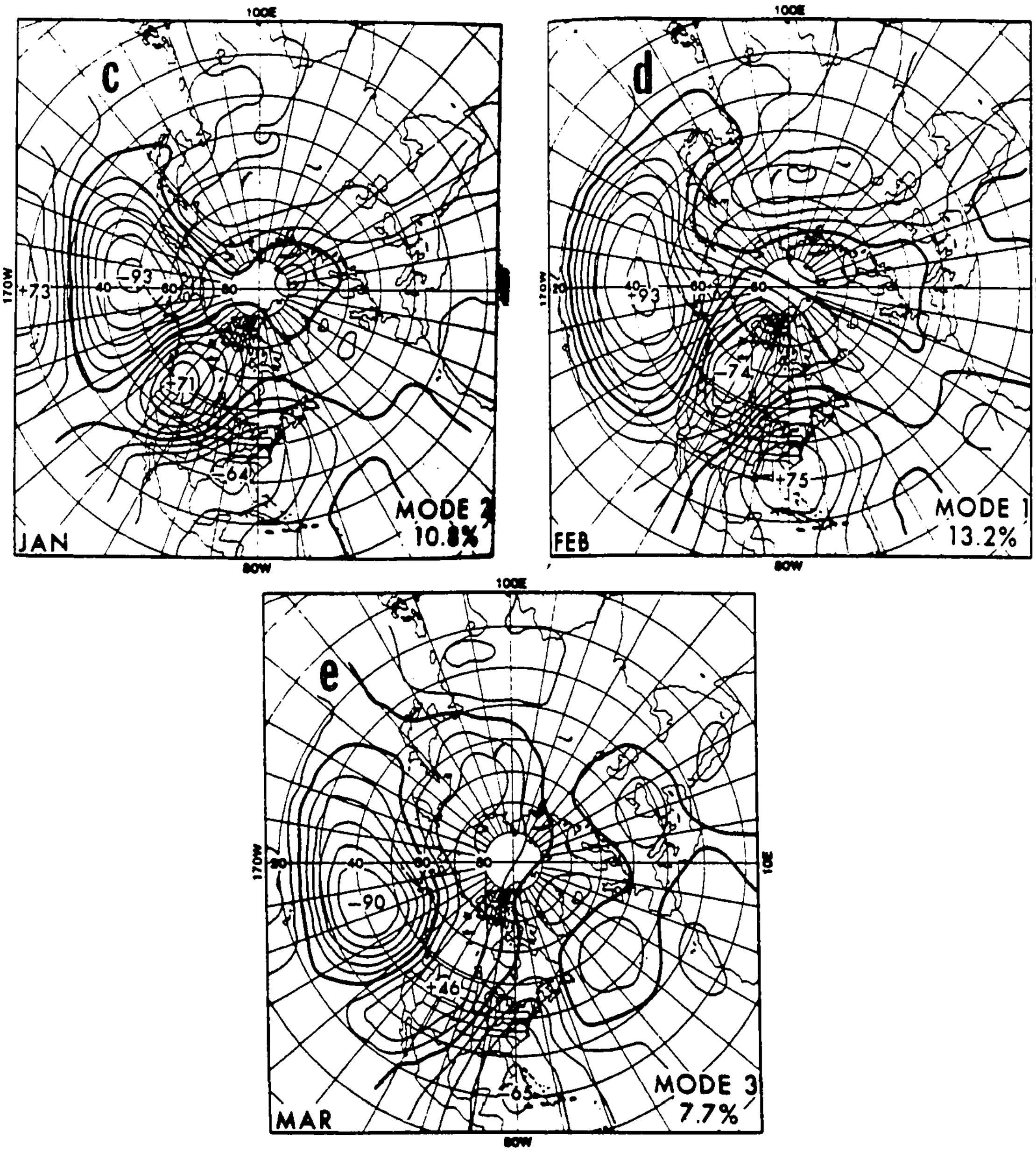


**Figure 2.4cont'd** The Pacific North American pattern-700mb anomaly. (c) January, (d) February, and (e) March structure (Barnston and Livezey, 1987).

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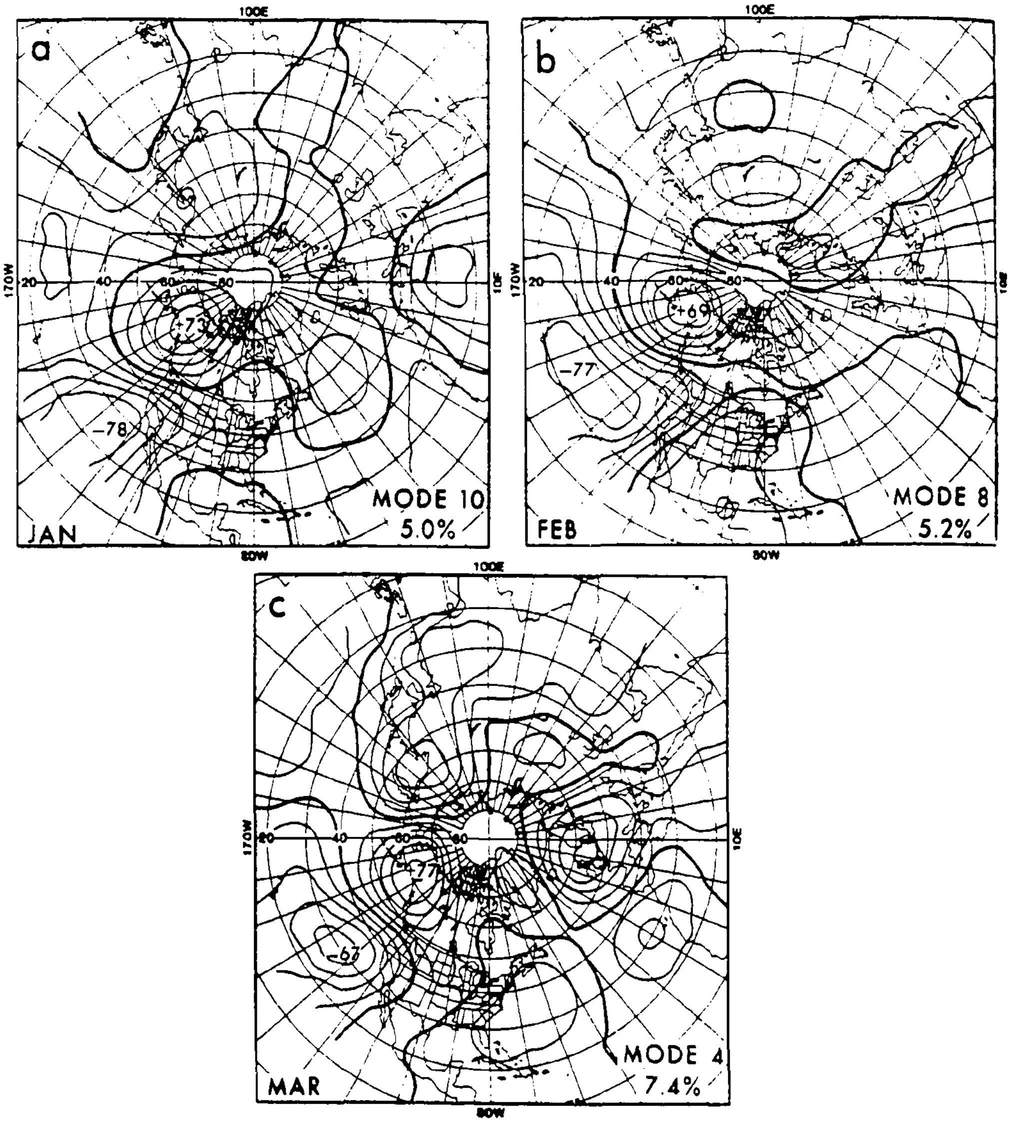


**Figure 2.5** The East Pacific pattern-700mb anomaly. (a) January, (b) February, and (c) March structure (Barnston and Livezey, 1987); see text for explanation of modes and percentages.

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pattern as defined in the winter circulation studies of Hsu and Wallace (1985). The main anomaly is a large center located over northern Asia around $70 - 130°E, 70 - 80°N$. A second feature is the more-migratory oppositely-signed anomaly existing over the Western Pacific or Central Asia. Its position appears to vary depending on time of season from $170°E, 35°N$ to $115°E, 45°N$. There is also some evidence of a third positive anomaly feature over the Western United States and Eastern Pacific. This Northern Asia anomaly pattern is evident in the circulation of all six winter months.

The final pattern to be discussed from BL's study (1987) is the West Pacific Oscillation (Fig. 2.7). The main feature of interest in this pattern is the strong anomaly centered near $170°E - 170°W$, $50°N - 60°N$. It appears as a meridianal "dipole" separated in the middle by a steep gradient. The north and south portion of the feature may have either a positive or a negative tendency, but they always appear with opposite signs. When the north sector is positive, the Alaskan interior is affected by strong northerly flow. When the top portion is negative, the state is affected by strong west or southwesterly flow.

Circulation patterns defined in smaller regional studies involving Alaska specifically are the next subject. Results discussed include the work of Moritz (1978), Putnins (1966), Overland and Heister (1980), and Yarnal (1985). While these are by no means exclusive, they are quite representative of the known literature in both method and result. Moritz (1979) and Yarnal (1985) used a second type of objective or "computer-assisted" method of classifying daily synoptic weather charts into specific categories. The processes were adapted from the techniques used by Lund (1963) and by Kirchhofer (1973). The Lund method involves the calculation of correlation coefficients between all possible pairs of maps to form a type of correlation matrix. Map pairs whose correlation score passes a user-determined threshold are determined to be similar. Maps are sorted into computer-designated basic categories based on these scores. The Kirchhofer method is quite similar to and, in fact, some feel that it is identical to the Lund method when it is broken down to its basic principles (Willmott,1977). The Kirchhofer method involves calculating the sum of squares differences between maps to determine

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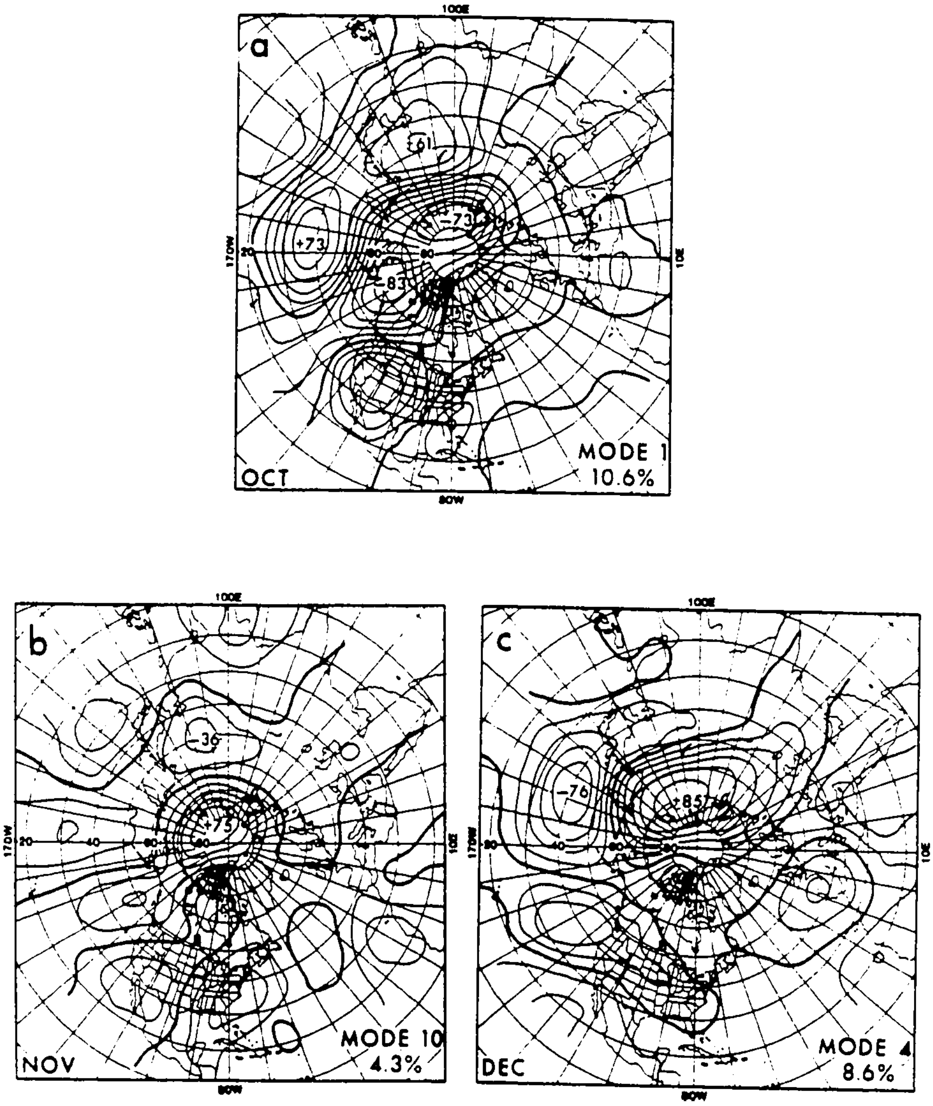


**Figure 2.6** The Northern Asia pattern-700mb anomaly. (a) October, (b) November, and (c) December structure (Barnston and Livezey, 1987); see text for explanation of modes and percentages.

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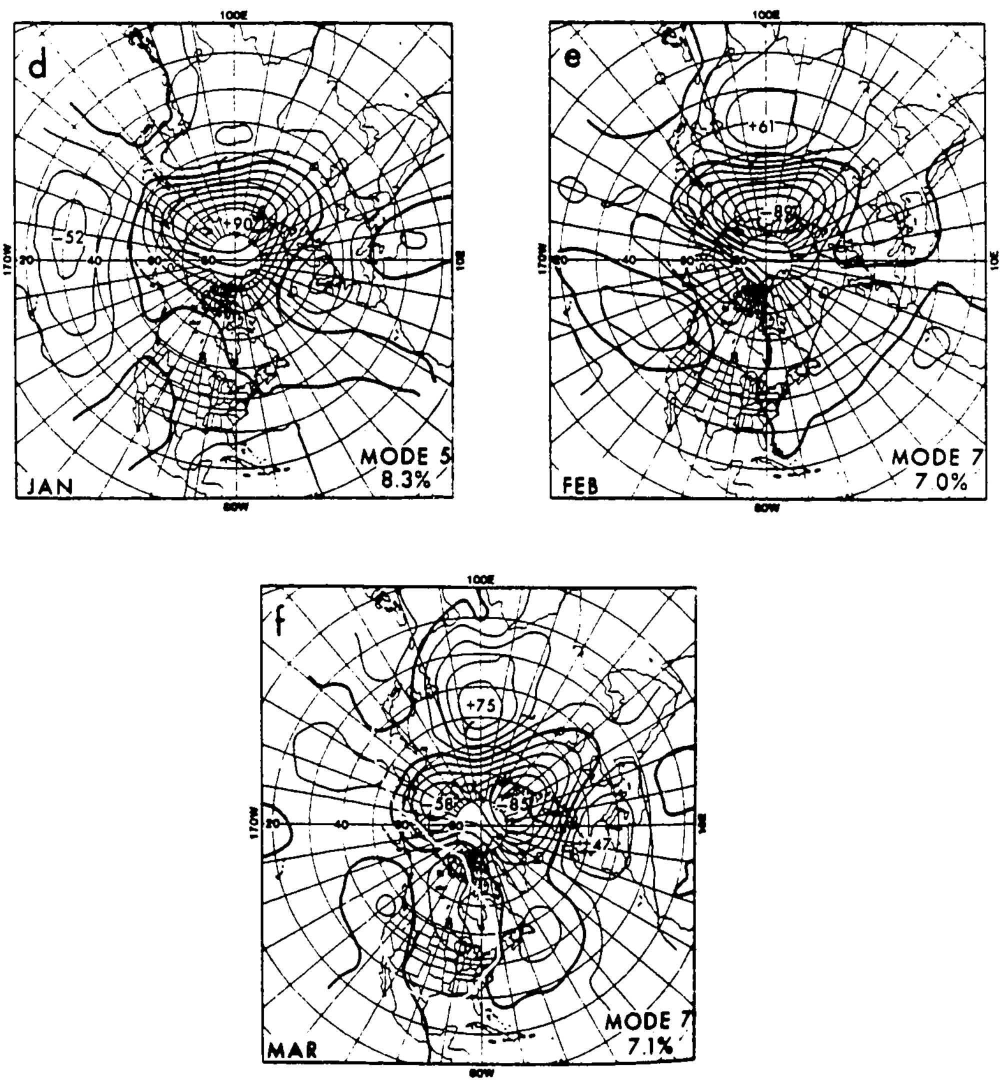


**Figure 2.6cont'd** The Northern Asia pattern-700mb anomaly. (d) January, (e) February, and (f) March structure (Barnston and Livezey, 1987).

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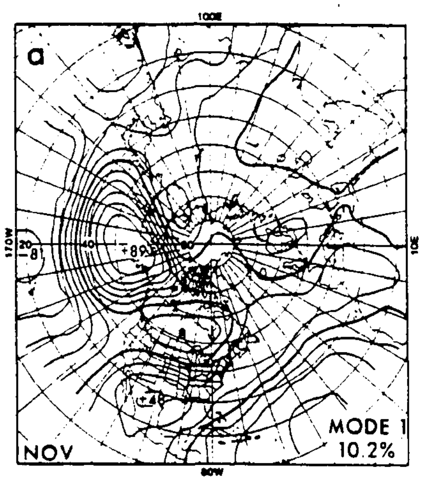


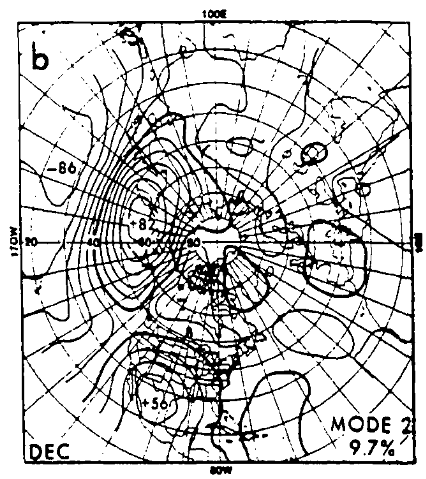


**Figure 2.7** The West Pacific Oscillation pattern-700mb anomaly. (a) November and (b) December structure (Barnston and Livezey, 1987); see text for explanation of modes and percentages.

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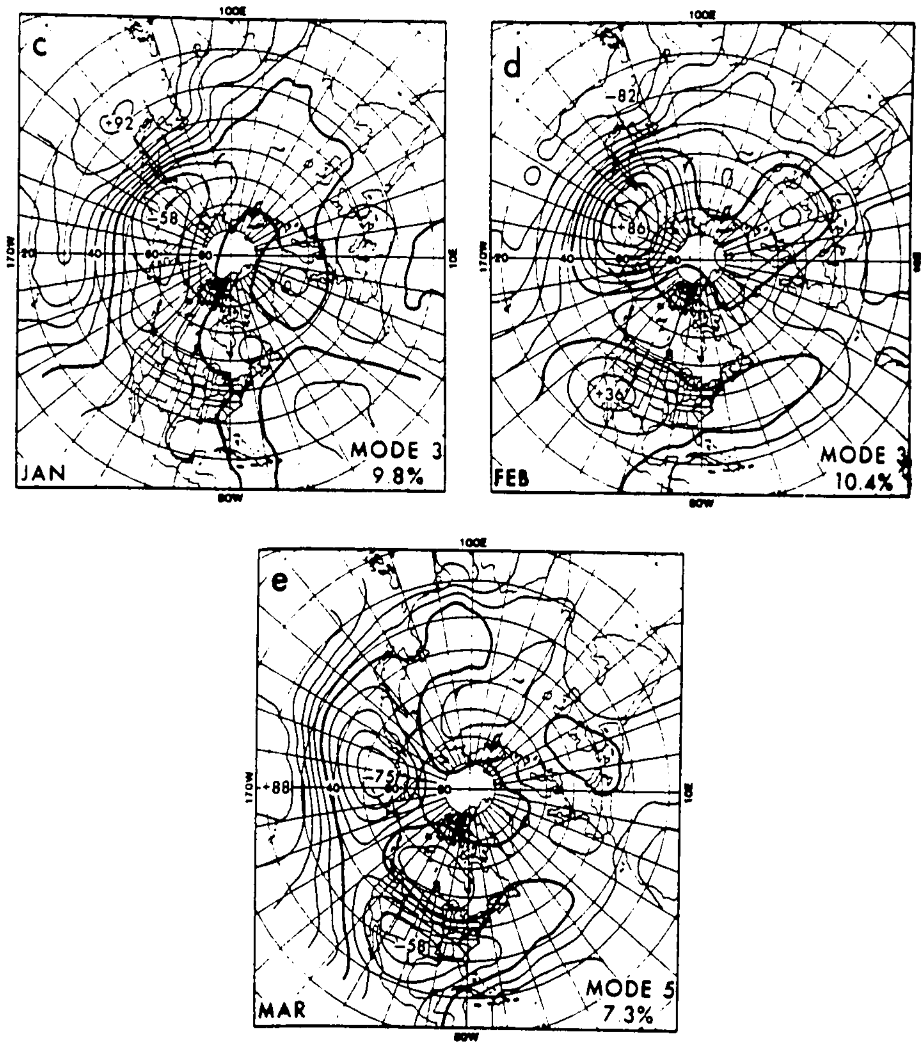


**Figure 2.7cont'd** The West Pacific Oscillation pattern-700mb anomaly. (c) January, (d) February, and (e) March structure (Barnston and Livezey, 1987).

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similarities. Synoptic maps are then sorted into computer-determined keyday categories based on user-set thresholds.

Moritz's work focused on the synoptic climatology of the Beaufort Sea area (Moritz, 1979). The atmospheric circulation climatology portion of his investigation was based on a regional sector ($60°N - 80°N, 120°W - 170°W$) of daily 12GMT surface level synoptic charts. The time period covers the entire year period of 1946-1974, although, due to computer limitations, a subset of data (October 1969- December 1974) was used to determine basic patterns. Five dominant winter patterns shown in Figs. 2.8a-e resulted from this computational process. Fig. 2.8a shows a fairly steep gradient along the northern half of Alaska resulting in strong zonal circulation. South of the gradient is an area of low pressure extending southward over the Gulf of Alaska region. An area of low pressure is located to the west of Cook Inlet. Fig. 2.8b shows a broad high pressure system centered slightly east of the Alaska-Canada (ALCAN) border and extending over interior Alaska. A fairly steep gradient oriented northeast to southwest is seen over the southwestern corner of the study region. Fig. 2.8c reveals an west to east elongated high pressure system centered in Canada. This feature extends across most of Alaska and the Bering Sea. Evidence of a low pressure system in the northeast Gulf of Alaska is seen as there is an area of tightly- spaced "zonal" isobars extending southward to the edge of the study domain. Two features of interest in Fig. 2.8d are the high pressure area over the Chukchi Sea and the broad relatively flat low pressure system over the southern half of Alaska. Fig. 2.8e is suggestive of what Fig. 2.8c might look like if the pattern in Fig. 2.8c was shifted several degrees to the north. A strong low pressure system is centered over the St. Elias Mountains along the northeast Gulf of Alaska. This produces an intense northwest/southeast-oriented gradient across the state from the system center to the Seward Peninsula. The northern half of the study area shows a hint of high pressure beginning to build eastward from Asia across the top of the low pressure system.

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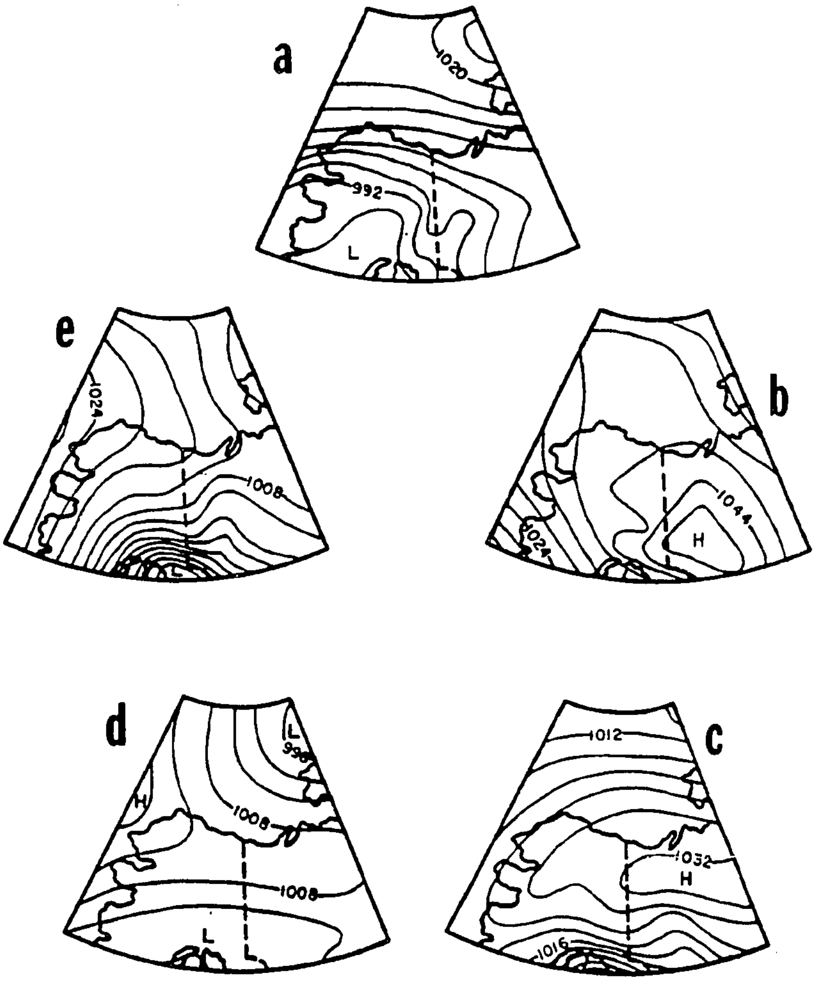


**Figure 2.8a-e** Surface level winter circulation patterns for the Beaufort Sea Coast of Alaska. Contours are 4mb (Moritz, 1978).

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From the work of Overland and Heister (1980) and Yarnal (1985), patterns based at two different atmospheric levels focusing on the Gulf of Alaska/ Northeast Pacific sector are defined. Yarnal's circulation study emphasized the winter 500mb daily geopotential height patterns of the Pacific Northwest from the 1948/49 season to the 1977/78 season. The application of a modified Kirchhofer scheme (Kirchhofer, 1973; Yarnal, 1984a,b; Key and Crane, 1986; Yarnal and White, 1987) to this data resulted in the definition of 18 typical key patterns. Three of these key patterns are shown in Figs. 2.9a-c. The first (Fig 2.9a) consists of a low pressure center over the north coast of Alaska, zonal conditions over the interior of Alaska, and high pressure over western Canada. The second key pattern (Fig. 2.9b) is characterized by a low pressure center over the ALCAN border and eastern Beaufort Sea. A southwest/northeast gradient extends across Alaska from a high pressure system in the east Pacific to the low in Canada. The dominant feature of Fig. 2.9c is a strong low pressure system situated over the central Gulf of Alaska. Secondary features include low pressure north of Barrow, Alaska and high pressure in the southeast corner of the study region.

Overland and Heister (1980) limited their efforts to the immediate Gulf of Alaska region. Their circulation classification techniques were both subjective and objective. Six key patterns were developed subjectively based on the results of a study of atmospheric circulation associated with North Pacific wind fields (Sorkina, 1963) and the surface-level pressure pattern catalog devised by Putnins (1966, 1969). The objective Lund technique (Lund, 1963) was also applied to surface-level digitized charts (1968-77) to determine a second set of patterns for comparison purposes. Both sorting techniques indicated similar results. Figs. 2.10a-d show the most prominent winter circulation patterns as defined by Overland and Heister (1980). The first (Fig. 2.10a) includes a large low pressure system centered in the Gulf of Alaska at $58°N, 148°W$. The northern sector of the study zone is suggestive of a slight ridge. The southwest corner of the domain indicates a second intense low pressure feature along the Aleutian Chain. The second chart (Fig. 2.10b) is almost entirely dominated by a low pressure system centered over the southern Alaska Peninsula

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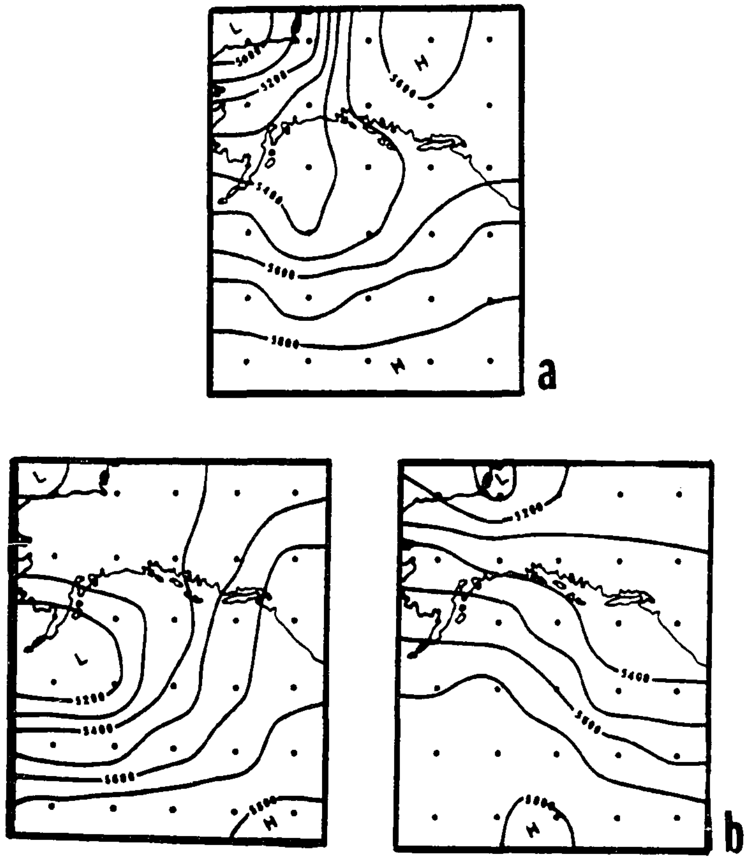

**Figure 2.9a-c** 500mb winter circulation patterns for the Pacific Northwest region. Contours are 100m (Yarnal, 1985).

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near $56° N, 160° W$. A weak high pressure feature is centered over western Canada at $65° N, 125° W$. Fig. 2.10c shows the eastern extreme of the low pressure characteristic of the first two patterns. The low center is off the coast of the Queen Charlotte Islands near $54° N, 138° W$. High pressure is located over the Seward Peninsula of Alaska and over northwest Canada. The fourth winter pattern, Fig 2.10d, is characterized by a strong high pressure feature positioned at $65° N, 128° W$. A tight gradient extends southwest over Alaska from this high pressure to the edge of the study domain.

A map classification compiled by Putnins (1966, 1969) in the late 1960's is the most comprehensive subjective presentation of the Alaskan circulation climatology. This climatology of circulation patterns is primarily surface-based; however, some consideration has been given to the anti-cyclonic/cyclonic nature of the associated flow at $500mb$. The time period involved in this investigation is January 1945 to March 1963. By means of visual sorting, "general situations were determined from weather maps such that every day of the period could be assigned to a specific baric pattern" (Putnins, 1966). Of the 22 categories of maps defined in this manner, three are quite dominant during the winter season. The first of the surface-level patterns, shown in Fig. 2.11a, is composed of four low pressure centers surrounding Alaska, a broad central Pacific high pressure feature, and a fifth low center over Eastern Europe. The second chart (Fig. 2.11b) has a low center over the Gulf of Alaska, an elongated high pressure feature along the southern edge of the Aleutian Islands, a low over the western Bering Sea, and a broad high pressure system centered near $75° N, 125° E$. The third map (Fig. 2.11c) is characterized by an intense low pressure system centered over the western tip of the Aleutian Island chain at $53° N, 175° E$ and an equally intense high pressure system over northern Canada centered at $66° N, 120° W$. A weaker occluding low pressure feature is situated between the over the Gulf of Alaska between the two major systems.

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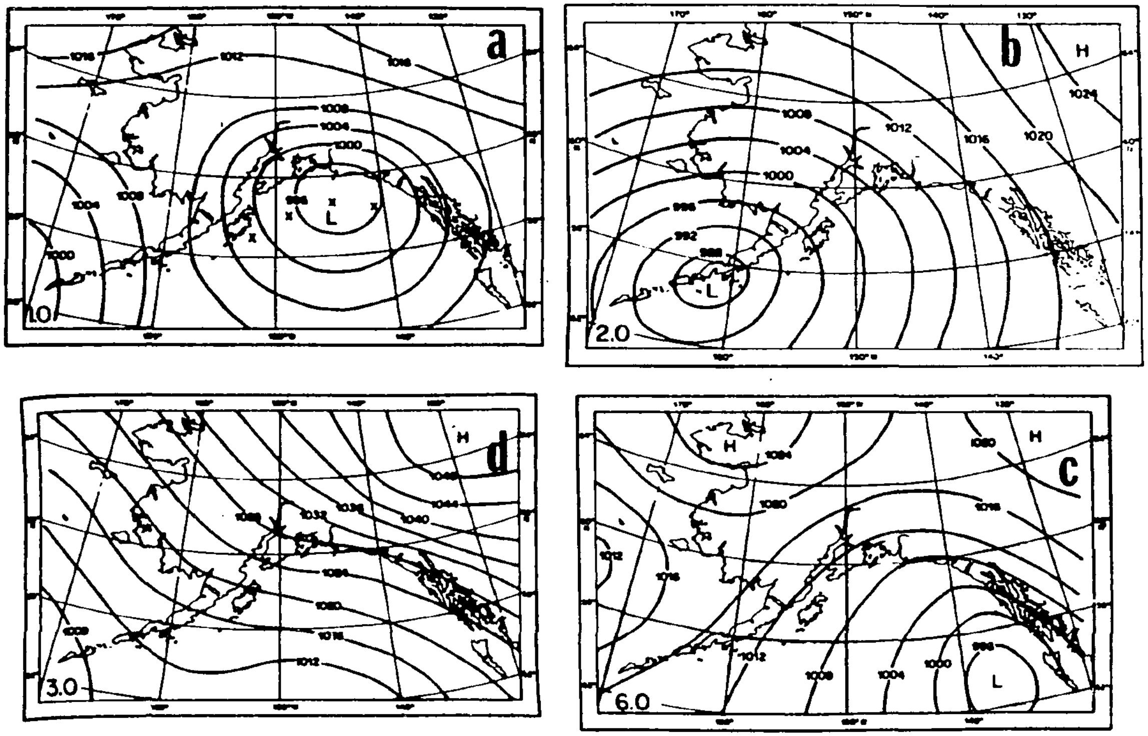
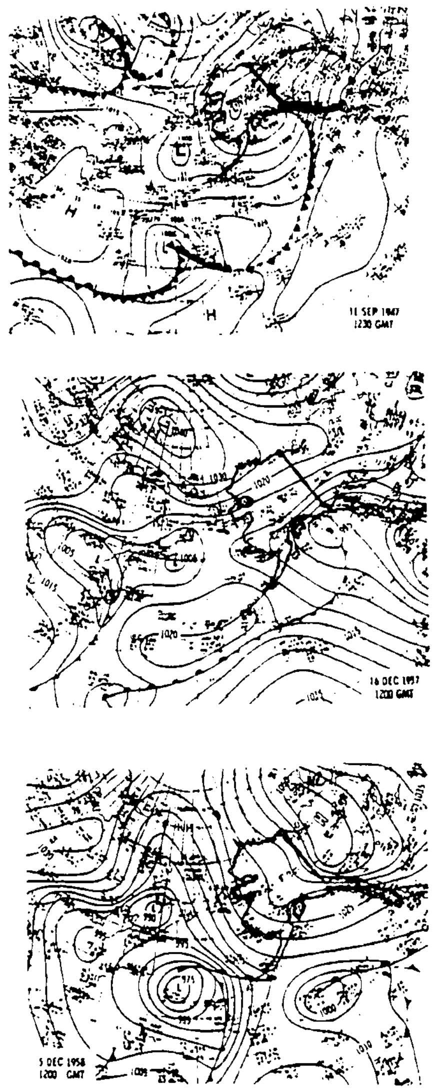



**Figure 2.10a-d** Northeast Gulf of Alaska study area and winter surface level circulation patterns. Contours are 4mb (Overland and Heister, 1980).



a

b

c

**Figure 2.11a-c** Prominent winter surface level circulation patterns- Alaska. From Putnins, 1966.

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### 2.2: Surface Climate

Alaska is characterized by one of the most diverse climate systems on the North American continent. The land mass stretches from $51^\circ N$ at the southernmost point in the Aleutian Island chain to $71^\circ N$ at Pt. Barrow on the Arctic coast. The state is bounded by Canada on the east, the warm waters of the Northeast Pacific Ocean to the south, the cool waters of the Bering Sea nearly 60° longitude to the west of Canada, and the cold Arctic Ocean to the north. Three major mountainbelt systems crisscross the state with peaks rising from near sea level to heights ranging from 1200m to more than 6000m. These provide the vast interior regions of the state with effective barriers from the maritime air of the surrounding ocean regions. On the northern shore, the Brooks Range separates the Arctic Ocean and coastal plain from the Interior. To the south, the Coastal Range forms an extended arc along the Northeast Pacific Ocean from the Southeast panhandle of the state to the Alaska Peninsula. The third system, the Alaska Range, forms the northern boundary for most Pacific-based moisture transport and the southern boundary for the immense interior region dominated by the Yukon river and its tributaries. The interior regions between the Coastal Range, the Alaska Range and the Brooks Range to the north are composed of comparatively flat, broad river valleys that stretch for hundreds of kilometers.

The surface-level winter climate of Alaska is also characterized by varying intensities of cold season meteorological phenomena. This is due primarily to four factors: the diversity of local topography, the range of incoming solar radiation, the extreme latitudinal and longitudinal area covered by the state, the surface-level inversions in the Interior, and the existence of both frozen and unfrozen water bodies nearby.

Winter solstice sunlight durations decrease from $5.5hrs$ of possible sunlight at Anchorage to $0hrs$ north of the Arctic Circle. This reduced amount of incoming radiation contributes to the persistence of cold temperatures and lack of diurnal temperature variability so characteristic of the

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Interior and Arctic regions. The unfrozen Pacific Ocean and southern Bering Sea allow for the presence of a moderate, moist climate along the southern coastlines. To the north, the frozen Arctic Ocean inhibits climate moderation along the Arctic coastal plain. The large interior basin is cut off from the influence of either extreme by the Alaska and Brooks Ranges.

The combined effect of ocean influence, complex topography, and large latitude-longitude coverage is apparent throughout the year, but the combination's influence is most predominant during the winter season. Winter may bring a temperature differential of as much as 100 degrees between the northern, interior, and southern reaches of the state. Coastal regions along the unfrozen Northeast Pacific Ocean experience temperatures below $-10°C$ only on rare occasions. The interior region and the arctic regions seldom observe temperatures above freezing, due to the low amount of solar radiation and the regions' distance from the moderating influence of unfrozen water. Precipitation may be equally variable, falling as drizzle or heavy rain in the southern regions, as moderately heavy snow in the Coastal/Alaska Ranges, as light snow in the Interior, or as light, wind-driven snow along the Arctic coast. Because of the diversity of weather observed during Alaska's winter, this general review of the climate is presented in terms of four broadly-defined (Hartman and Johnson, 1984; Hare and Hay, 1974) climate zones (Fig. 2.12) — Arctic, Continental or Interior, Transitional, and Maritime.

The Arctic region is characterized by temperatures below $-17°C$ throughout the winter. Average January temperatures (Fig. 2.13) range from $-34°C$ to $-23°C$. Precipitation values are extremely low as conditions are unfavorable for generation of heavy precipitation events. Air mass temperatures are generally less than $-40°C$ and there are no significant unfrozen moisture sources in the region. The Arctic Ocean along the northern coast of Alaska remains ice-covered for more than six months per year. Prevailing winds blow onshore from the North, Northeast, and Northwest bringing dry polar air into the region. Although the accuracy of snow measurement in the Arctic

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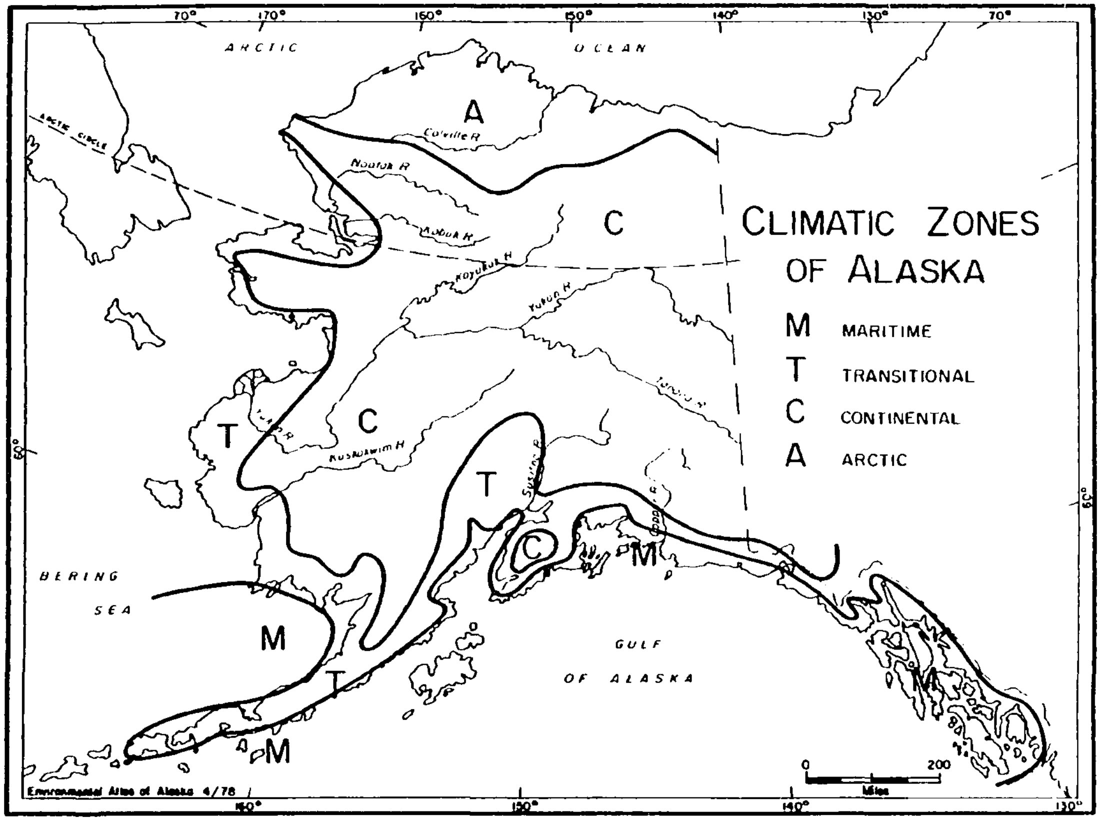


**Figure 2.12** Basic climate zones of Alaska. From Hartman and Johnson, 1984.

is questionable due to the wind activity, records (Fig. 2.14) indicate annual snowfall values in the $508 - 1000mm$ range.

The Interior region situated between the Alaska and Brooks Ranges is best labeled continental (Fig. 2.12). January temperatures in this region may be colder than $-62°C$ or as warm as $4°C$. It is not unusual for a temperature of $-40°C$ or lower to be observed at least once during the winter in this zone. The coldest portion of the winter in the Interior is considered to be in late January. The Interior basin is also prone to strong low-level temperature inversion episodes and ice fog (Bowling, 1967). However, recent observations have indicated a decrease in the occurrence of dense ice fog in association with warmer winter temperatures over the last ten years.

Precipitation totals are much lower than those along the temperate Gulf Coast, but they are not as small as those along the Arctic Coast. Annual snowfall amounts (Fig. 2.14) range from $762mm$ to $2540mm$ in the Interior.

Between the Interior basin and the coastal regions is a transitional zone. As shown in Fig. 2.12, this includes the area north of Bristol Bay along the Bering Sea, the inland Alaska Peninsula, and the central Alaska Range. This zone shelters the Interior region from the northward flow of maritime air. Temperatures are slightly lower than those of the coastal region; but, they are not as extreme as those observed in the Interior or Arctic. The range of mean January temperatures is from $-22°C$ to $-4°C$. Mean annual snowfall in the zone may be in excess of $5080mm$ along the windward slopes of the mountains and as low as $1016mm$ along the Bering Sea coast (Fig. 2.14).

To the south along the Gulf of Alaska coastline, the climate is maritime (Fig. 2.12). The local climate is influenced by the presence of unfrozen water and by the Coastal Mountain Range system that bounds the coastal region. Temperatures are considerably higher than those observed in the Interior and Arctic regions. January values average between $-12°C$ and $-1°C$. Precipitation values are quite high due to the presence of the mountains and the prevailing onshore flow of marine air. Although the precipitation may be in the form of snow, rain, or a mixture of the two, the annual

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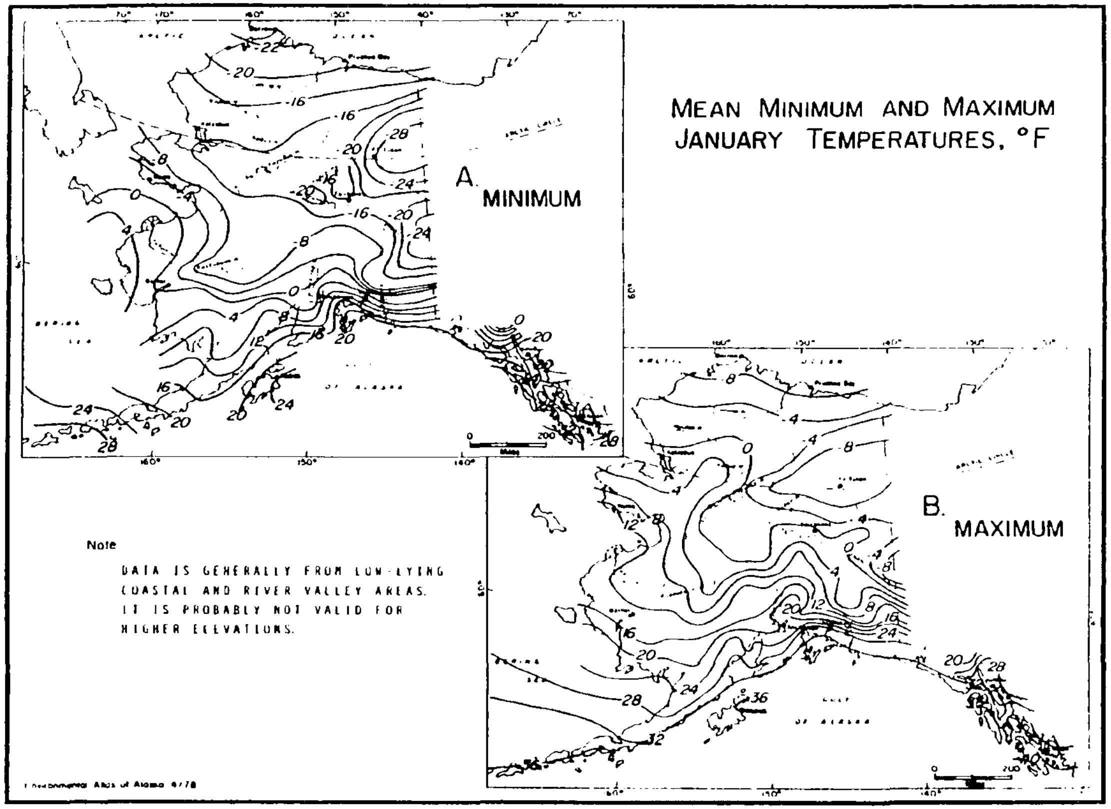


**Figure 2.13** Mean maximum and minimum January surface level temperatures in Alaska. units are $^\circ F$; (Hartman and Johnson, 1984).

MEAN ANNUAL SNOWFALL IN ALASKA

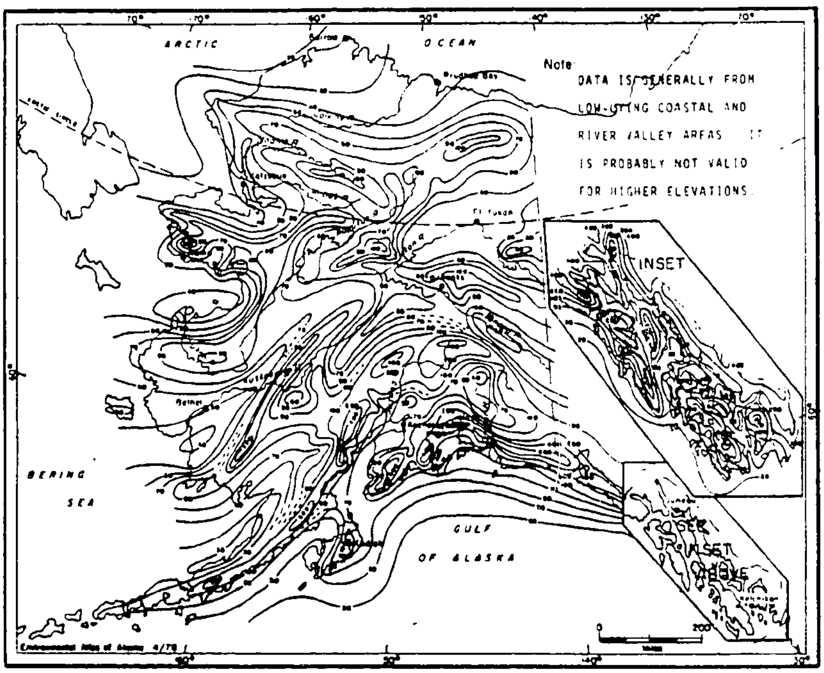


**Figure 2.14** Annual snowfall totals in Alaska. units are in *inches*; From Hartman and Johnson, 1984.

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snowfall exceeds $5080mm$ in the coastal mountains, especially along the central and northeast Gulf of Alaska. The annual snowfall in the St. Elias and Chugach Mountains supports the existence of the largest glaciers in North America (Post and LaChapelle, 1971).

The climate of Alaska is by no means static. In reality, there are several indications of interannual or longer-scale fluctuations in the basic state. One of these is the surface temperature record over the last thirty years. Observations compiled by Bowling (1988), Wise (1988), and others suggest that the early 1980's winters were among the warmest in this century. Accompanying the warmer winters has been an apparent decrease in the frequency and intensity of ice fog in Fairbanks (Bowling, pers. comm.). Further examination of site-specific records seems to hint at a ten-year cycle of warming and cooling throughout the state's regions. The ocean provides a second indicator as these land-based trends appear to be in conjunction with fluctuations in North Pacific temperature behavior. The long-term time series of sea surface temperatures indicates a considerable warming of $.1°C/yr.$) in the Gulf of Alaska surface temperatures since the 1970's (Royer, pers. comm.). Finally, well log records from permafrost indicate a warming of $1.5°C - 3.0°C$ in the Arctic permafrost (Lachenbruch *et al.*, 1988) over the last century followed by a slight cooling in the early 1980's (Osterkamp, 1987). There is also evidence of warming in the discontinuous permafrost of the Interior zone. While the response time in permafrost is much slower than that of other climatic indicators, the records are quite pertinent in that they provide evidence of long-term trends in Arctic climate behavior.

Finally, the effect of Alaska's winter climate system is not limited to the state's region, alone. The confluence of the frigid southern Bering Sea and the comparatively warm Northeast Pacific along the Aleutian Island chain forms one of the most dynamic regions (Figs. 2.15a,b) of winter cyclogenesis and cyclolysis in the world (Dole and Gordon, 1983; Gyakum *et al.*, 1989; Namias, 1975). It is a major source region for the Pacific winter storms that affect the Northwest coast of

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Canada, the contiguous 48 United States, and the rest of the North American continent (Namias, 1969; Namias, 1978).

### 2.3 Summary

The dominant circulation patterns associated with the arctic/Alaska winter season include a low pressure system or a negative anomaly over the confluence of the North Pacific and Bering Sea, high pressure or a positive anomaly over Northern Asia, low pressure or a negative anomaly over the Northeast Gulf of Alaska, and high pressure or a positive anomaly over the northern half of Alaska. In terms of surface climate, the basic characteristics of the different geographic regions indicate a great deal of spatial and temporal variability in temperature and precipitation throughout Alaska. At this point, Alaska's climate record is very limited in space and time, and very little is understood about the long-term climate variability.

As was mentioned at the outset of this chapter, this review is meant to serve only as a summary of what is currently known about the synoptic climatology of Alaska. In short, it provides the stepping-off point for the research presented in the following chapters of this thesis.

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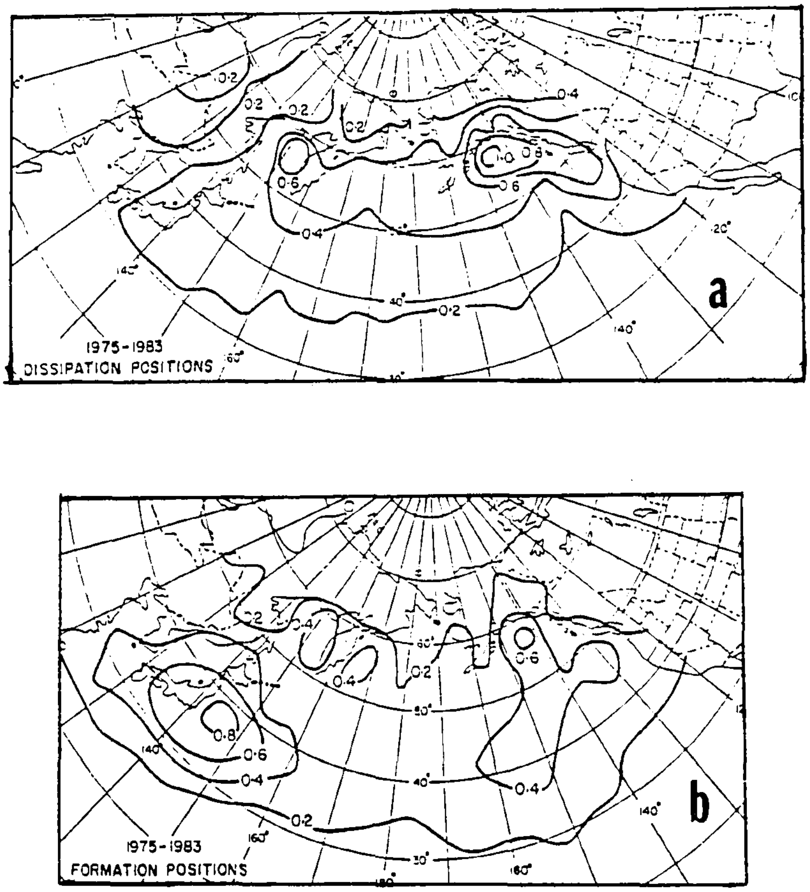


**Figure 2.15a,b** Favored positions of all extratropical cyclone formation and dissipation during the winter seasons from 1975-1983. (a) Dissipation positions: Units are number of cyclones per thirty days per 5° × 5° latitude-longitude quadrilateral (contours are spatially-smoothed frequencies of occurrence); (b) as in (a) but for formation positions (Gyakum *et al.*, 1989).

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## Chapter 3: Classification of 700mb Anomaly Patterns

Step 1 in the construction of a regional synoptic climatology is to determine the basic atmospheric circulation patterns that affect the region. In the previous chapter, various methods of classification processes and different scales of climatologies were discussed. In this chapter, a modified Kirchhofer (1973)/Lund (1963) classification scheme is used to create a catalog of $700mb$ geopotential height anomaly patterns common to Alaska's winter season.

### 3.1: Data Processing

#### 3.1.1: Atmospheric Level

The data used in this pattern climatology are adapted from the $700mb$ Northern Hemisphere analysis charts (National Meteorological Center) that have been interpolated by the National Center for Atmospheric Research (NCAR) to a $5° \times 5°$ longitude-latitude grid (Jenne, 1975) of geopotential heights. Both 12GMT and 00GMT data are included in the analysis process. The $700mb$ level was chosen because it retains some of the features of the surface-level circulation without being directly affected by the local topography or boundary-layer climate. The level also has flow characteristics similar to the higher atmospheric levels. Furthermore, the $700mb$ level flow is thought to be a major transport mechanism (National Weather Service Forecast Office-Fairbanks, pers.comm.; Bowling, 1987) for moisture reaching the interior of Alaska. The $700mb$ level is also the standard analysis level for National Meteorological Center research as the level explains both the dynamical and



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thermal effects of the lower atmosphere. Finally as it is the level of choice in almost all of the more recent Northern Hemisphere atmospheric circulation studies, using the $700mb$ level maintains continuity with the current literature.

### 3.1.2: Grid Setup

The initial NCAR Northern Hemisphere $700mb$ geopotential height grid was dimensioned to be $72 \times 19$ with gridpoints located 5° apart. The large grid was immediately reduced to a $72 \times 10$ grid in order to form a more regional-scale domain focusing on the Arctic/Sub-Arctic region. The $72 \times 10$ grid correponds to the region bounded by $40° N - 85° N$ and $0° E - 360° E$. Further examination of the data revealed a large amount of missing data at $85° N$ from 1947 to 1970. Because of the amount of missing data, it was decided not to attempt any interpolation to fill the void. Rather, a decision was made to shrink the grid by 5° latitude. A drawback of this action is that the shorter latitude dimension limits the complete resolution of possible high amplitude polar features. However, the advantage of a complete set of data and a single, consistent interpolation scheme was thought to outweigh this slight resolution limitation, especially as the grid reduction was only 5°. The resulting dimensions of the $5° \times 5°$ grid (Fig. 3.1) used in initial classification processing were $72 \times 9$ or $0° E$ to $360° N$, $40° N$ to $80° N$.

### 3.1.3: Time Period

The original NCAR $700mb$ geopotential height gridpoint data was available on tape for each twelve month time period beginning in 1947. However, there has been debate concerning the quality and accuracy of the early years of this record. During the first half of this century, the Arctic circulation was usually analyzed exclusively as a broad high pressure system (Moritz, 1979;; Barry and Perry,

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Initial Region of Study

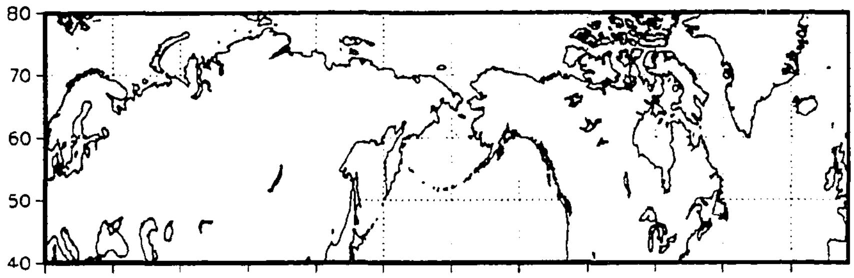


**Figure 3.1** **Initial geographic region of study.** $0 - 360°E \times 40 - 80°N$.

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1973). Research and better observation techniques developed in the 1950's proved this to be quite incorrect. In an effort to avoid the questionable early data, the data prior to 1956 were deleted from the set for this study. In choosing the length of data to be used, consideration was first given to the integrity of the data and then to the amount of data. While computer resources available for this study were quite generous, they were not unlimited. The largest possible set of data usable for initial analysis was determined to be a thirty year period of no longer than six months per year or a fifteen year period of 12 months per year. The thirty year period of data was chosen for the classification analyses because this length of time is generally considered to be the shortest period acceptable for calculation of mean climatic variables. A review of the surface climate phenomena suggested that the most variable six month "season" in Alaska was the period from October 1 to March 31. Recent research also suggested that this period was the more dynamic "season" in terms of known large-scale atmospheric circulation behavior (Namias, 1975; Tanaka, 1982; Anderson *et al.*, 1988; Dole and Gordon, 1983). Additionally, "greenhouse" models predict temperature changes to be the largest at high latitudes in the winter (Spelman and Manabe, 1984; Bryan and Spelman, 1985; Walsh and Chapman, 1989).

Based on these supporting factors and general interest in winter season climate variability, the winter six month period from October 1 to March 31 of the years 1956-1986 was designated for further analyses.

### 3.1.4: Anomaly Setup

Once an overall time period had been decided upon, an appropriate phenomenon frequency or period had to be determined. Although the $700mb$ data were available in twice-daily format, monthly-scale data were calculated to serve as the basic pattern frequency scale. This low-frequency variability with a typical time scale of a month is a recent central subject in general circulation research. However,

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the higher frequency phenomena have not been entirely disregarded in the later investigation of relationships between circulation and climate.

Monthly scale data were chosen for several reasons. First, the monthly-scale data could be easily correlated with regional monthly mean climate data to form a low frequency description of climate behavior. Second, the month-scale patterns were smoother than the daily patterns as the higher frequency components of the wave features were removed (Blackmon, 1976; Sawyer, 1970; Hoskins and Pearce, 1983; Holton, 1979; Gill, 1982). The smoother patterns would enhance the probability of classification into realistic basic pattern categories by statistical means. Finally, the choice of month-scale was also supported by the most recent full-hemispheric studies (Barnston and Livezey, 1987; Horel, 1981; Blackmon *et al.*, 1984a,b; Namias and Cayan, 1981).

To create a month-scale pattern, the twice-daily gridpoint data were averaged into a monthly mean grid. At least 80% of a month's data had to exist for a month to be considered complete and an average grid to be created. If less than 80% of the month's data existed, the month was flagged and none of that specific month's gridpoint data were used in further analyses. After removing "bad" months' data, there were 169 out of a possible 180 months left in the data set.

Once the monthly patterns were created, it was possible to calculate long-term ($30yr$) means for each of the six winter months and finally the anomaly patterns to be used in the pattern classification procedure. Long-term mean grids were determined by averaging the individual season monthly mean patterns over the length of their record ($30yrs$ is maximum). The resulting six long-term mean patterns (Figs. 3.2-3.7) formed the basic mean state for the anomaly pattern calculation. Temporal anomaly patterns were then determined using

$$\Phi^{*} = \Phi - \bar{\Phi} \tag{3.1}$$

where $\Phi$ is individual monthly mean geopotential height field, $\bar{\Phi}$ is the thirty-year monthly

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mean grid, and $\Phi^*$ is the month anomaly field. All gridpoint height units are in meters.

In order to retain some aspects of the higher frequency circulation phenomena in this synoptic climatology study, pentad anomalies were also computed. These anomalies are in approximate correspondence with the medium-frequency phenomena defined by Blackmon filtering techniques (Blackmon, 1976). The pentad or five-day scale of phenomena has been shown to have some importance in the prediction of synoptic scale events (Namias, 1975) that seemingly contribute to the variability found in regional monthly mean climate. Because of this association, these pentad patterns were used to further define extreme episodes in the surface climate record where possible relationships between climate and circulation were explored (see Chapter 5).

This choice of anomaly patterns as the basic circulation pattern format provided two immediate primary advantages. It would allow one to disregard the underlying seasonal cycle in the data. This would make it possible to compare March data to December data and so forth as the magnitude of departure remained unchanged. In other words, a $20m$ departure would still be a $20m$ departure regardless of whether it occurred in March or December. Second, the anomaly format would also allow one to visualize how different an individual month was from its respective long-term mean. The only disadvantage of using anomaly patterns was that the objectively-determined prominent patterns might be more difficult to interpret.

### 3.2: Classification Procedure

The classification scheme to be applied to the anomaly pattern data set is an adaptation of the Lund (1963)/Kirchhofer (1973) method. As mentioned in Chapter 2 of this thesis, this method employs a simple linear correlation to determine similarities between pairs of maps. The method's purpose is to classify individual maps into categories based on similarities between maps as determined by a correlation coefficient calculation. It is a type of pattern recognition technique whose "best use is for

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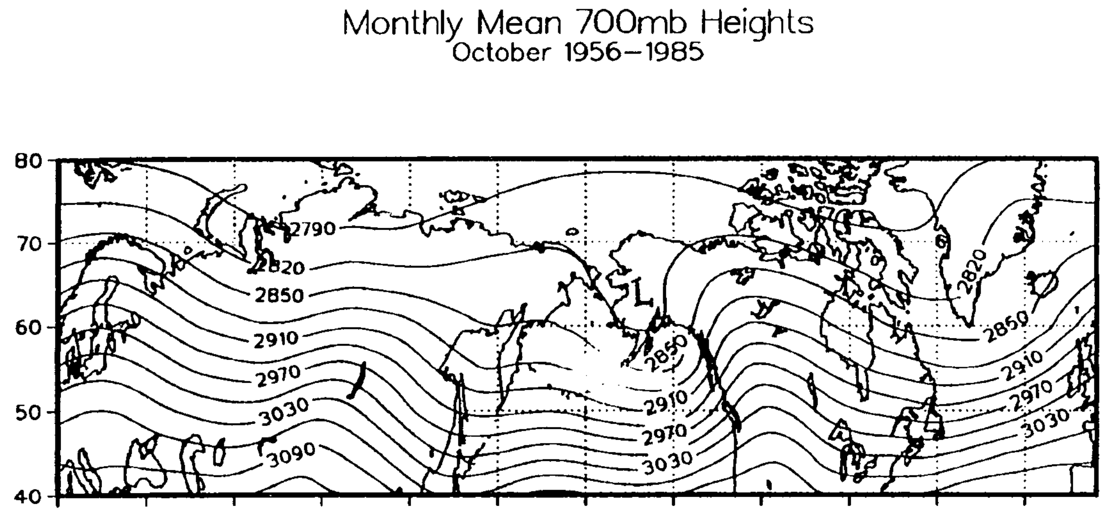


**Figure 3.2** Long-term (thirty-year) monthly mean $700mb$ geopotential heights- October 1956-1985. units are meters; contours are $30m$.

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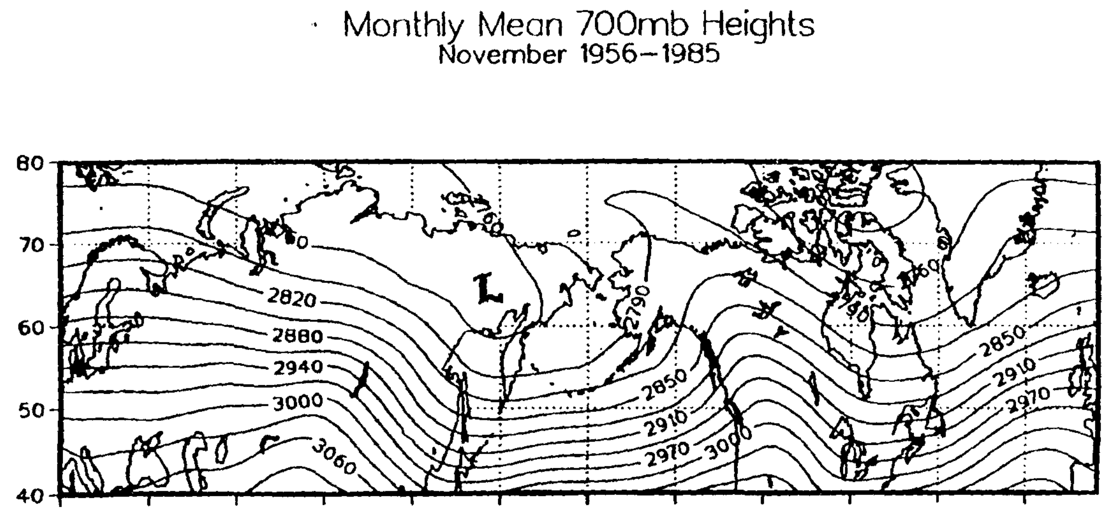


**Figure 3.3** Long-term (thirty-year) monthly mean 700*mb* geopotential heights- November 1956-1985. units are meters; contours are 30*m*.

Monthly Mean 700mb Heights
December 1956–1985

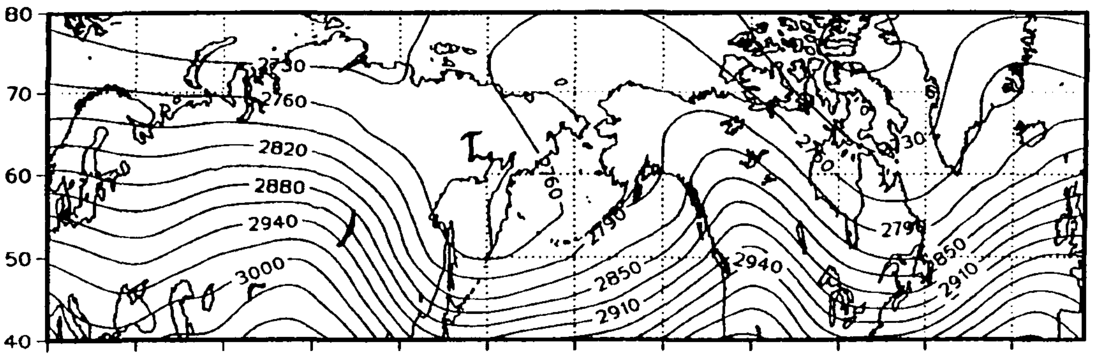


**Figure 3.4** Long-term (thirty-year) monthly mean $700mb$ geopotential heights- December 1956-1985. units are meters; contours are $30m$.



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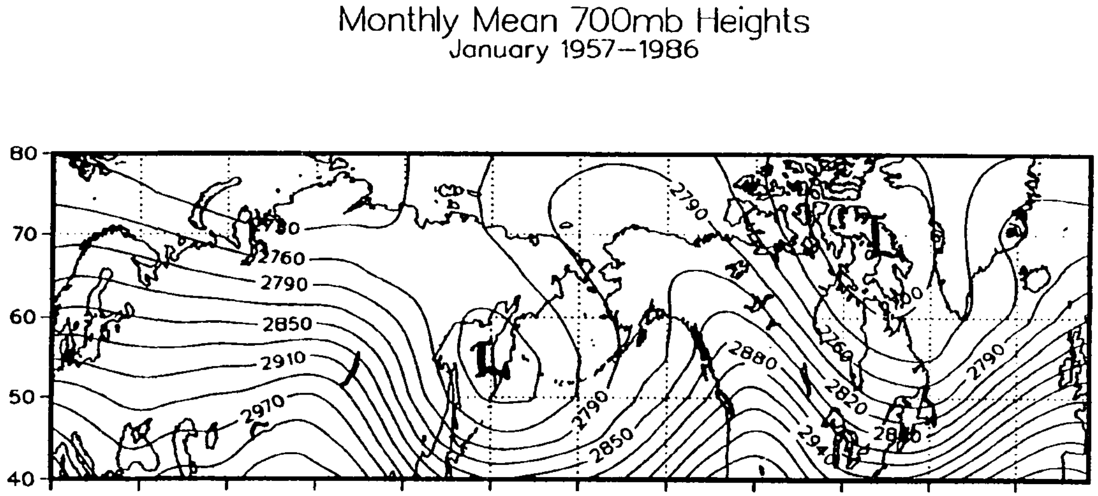


**Figure 3.5** Long-term (thirty-year) monthly mean $700mb$ geopotential heights- January 1957-1986. units are meters; contours are $30m$.

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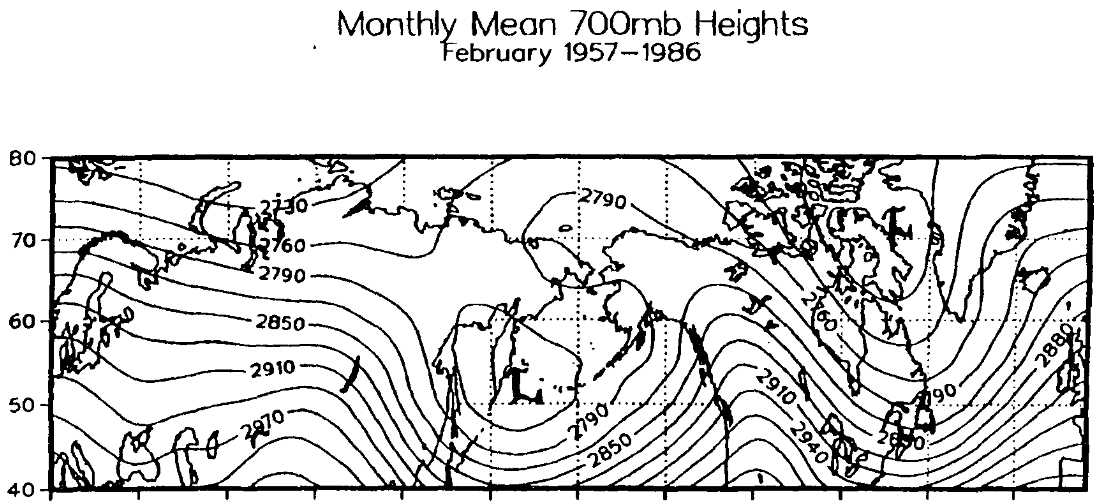


**Figure 3.6** Long-term (thirty-year) monthly mean 700*mb* geopotential heights- February 1957-1986. units are meters; contours are 30*m*.

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Monthly Mean 700mb Heights
March 1957–1986

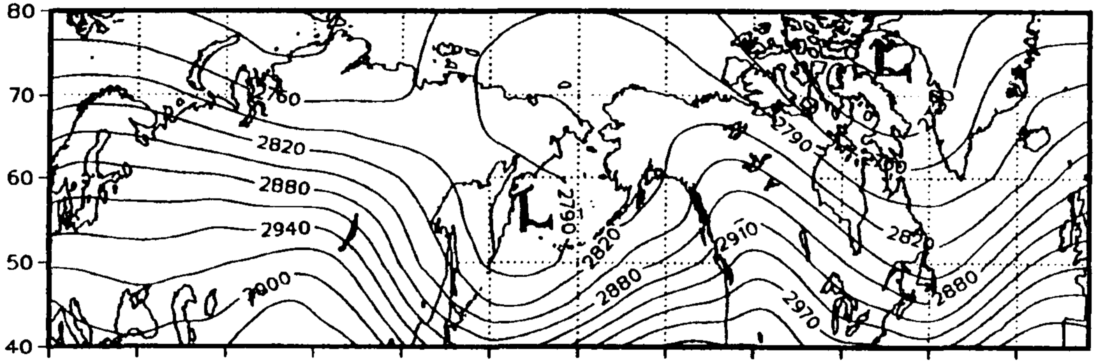


**Figure 3.7** Long-term (thirty-year) monthly mean 700*mb* geopotential heights- March 1957-1986. units are meters; contours are 30*m*.

identifying reappearing map patterns and stratifying situations for further study" (Lund, 1963). The method was chosen for its simplicity both in terms of calculation and in terms of interpretation of output. It is possible to readily assign individual maps to basic pattern categories without worrying about favorable eigenmode representation (Karl *et al.*, 1982) of patterns as one might with the use of a rotated principal component analysis technique (Barnston and Livezey, 1987; Horel, 1981).

The pattern sorting method used here is an objective or rather, a "computer-assisted" (Yarnal and White, 1987) technique, although, as with any known classification scheme, there is some subjectivity involved (Key and Crane, 1986; Yarnal, 1985; Yarnal and White, 1987; Yarnal, 1984a,b). In this case, the subjectivity shows up in the user-set thresholds for correlation coefficient limits and minimum association size for basic pattern designation. By using the largest possible database as suggested by Yarnal, the bias has been minimized as much as possible.

The version of the Lund (1963)/Kirchhofer (1973) map classification process used in this thesis is as follows:

1. Calculate correlation coefficients, $r_{AB}$, (Eq. 3.2) between all pairs of maps (i.e. map A and map B) to form a 169 × 169 matrix of correlation values. The 169 × 169 matrix is reduced after each basic pattern has been determined.

$$r_{AB} = \frac{\sum_{i=1}^{9}\sum_{j=1}^{22} A_{ij}B_{ij}}{\left[\sum_{i=1}^{9}\sum_{j=1}^{22} A_{ij}^2 \sum_{i=1}^{9}\sum_{j=1}^{22} B_{ij}^2\right]^{1/2}} \tag{3.2}$$

2. Select the map which has the highest number of maps correlated with it at an $r_{AB}$ value greater than the set threshold. If the number of maps similar to the map is greater than a set threshold, the map is designated Basic Anomaly Pattern 1.

3. Remove Basic Anomaly Pattern 1 and all similar maps from the data set.

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4. Repeat step 1 with the remaining data set. Repeat step 2 to obtain Basic Anomaly Pattern 2. Repeat step 3 to further reduce the data set. Continue this process until it is no longer possible to satisfy the similar number of maps threshold.

5. Recalculate the correlation coefficients between the basic anomaly patterns and each of the individual maps. This time the matrix of correlation values is not reduced. However, the same thresholds are used as before. If an individual anomaly pattern is determined to be similar to more than one basic anomaly pattern, it is cataloged with the pattern it is most similar to, that is, the basic pattern with which it had the largest correlation coefficient value. The purpose of this step is to insure proper classification of patterns which may be more similar to a "later-determined" basic anomaly pattern in the initial sorting.

6. The final basic anomaly patterns and their related individual anomaly patterns were cross-checked subjectively to determine how well the routine was able to distinguish between patterns and how valid the classification was in terms of known meteorological circulation.

A note of caution to those who might attempt to duplicate this process for a large data set—the computer resource demand is *quite* large in terms of time and processing space requirements. Others have applied the Kirchhoffer/ Lund technique to subsets of data in the initial basic pattern definition stage in order to alleviate this restriction. However, based on the findings of Yarnal and White (1987) and Key and Crane (1987), it was important to use the entire data set throughout the process so as to limit the subjectivity and other possible biases in the selection procedure.

Several "runs" of this procedure were performed to ascertain the stability of the computer's sorting and to insure the most realistic classification output. While this is a true computer sorting technique, several crucial subjective threshold decisions that directly affected the output had to be made. As mentioned earlier, these choices included correlation coefficient value for similarity and number of maps necessary to denote a basic pattern category. If a correlation coefficient threshold is too high, very few maps are classified. If it is too low, the true similarity between maps becomes

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questionable. Values of 0.6, 0.7, 0.8 were tested. In his original study, Lund (1963) chose 0.7 for this threshold. Other studies (Bradley and England, 1979; Hoard and Lee, 1986; Overland and Heister, 1980) have employed values ranging from 0.5 to 0.9. A correlation coefficient value of 0.6 was used in this thesis. A similar problem exists with the choice of minimum group size for basic pattern designation. Group sizes of 5, 10, 16 maps were tested. The five map threshold was used in this study.

A third decision of importance to this regional study was the designation of a grid size or rather how much of the overall global area the $5° \times 5°$ gridpoint data should cover. This grid area size variation was found to have a fairly large effect on the definition of basic anomaly pattern categories. The initial full-hemisphere, $40°N - 80°N$ grid allowed features far from the region of Alaska to affect the choice of basic pattern categories and individual map classification. A map may be extremely similar to another over Alaska, but very different over western Europe. Are these maps similar or not? The computer sorting denies the similarity when in fact the maps were similar over our study domain. It is therefore very important to select the appropriate region for examination before the classification process is begun. However, it is equally important not to deny the connection between regional phenomena and the larger global-scale circulation. In an effort to find a compromise, the classification scheme was applied to four different longitudinal grid dimensions — full hemisphere, half-hemisphere, $140°E$ to $115°W$, and $40°N$ to $80°N$. The final grid dimensions used to determine the results presented in this thesis were $140°E$ to $115°W$, $40°N$ to $80°N$ or a $22 \times 9$ gridpoint rectangle (Fig 3.8).

The ultimate goal of all of these subjective choices was to use the most stringent similarity thresholds possible to classify the largest number of maps while at the same time capturing meteorological reality in the output. The chosen thresholds resulted in the classification of 131 of 169 or 78% of the maps into ten representative basic anomaly pattern categories (Table 3.1, Fig. 3.9).

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Region of Study

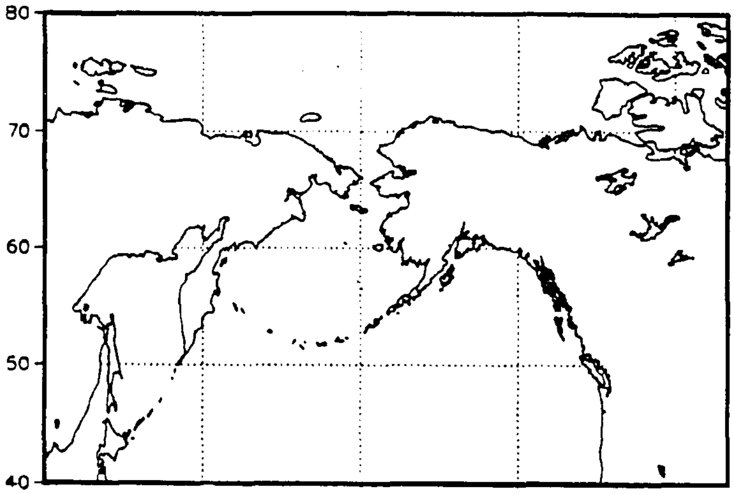


**Figure 3.8** Final geographic domain used in anomaly pattern classification scheme. a $22 \times 9$ point grid with points spaced at 5° intervals covering the area within 140° $E$, 115° $W$, 40° $N$, and 80° $N$.

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**Table 3.1** Anomaly pattern classification results. Original refers to the map distribution during the initial Basic Anomaly Pattern selection process; Final refers to the map distribution after all maps were sorted into their respective "best" Basic Anomaly Pattern category; minimum thresholds used in the classification process: $r_{AB} = 0.6$ and 5 maps per category.

| Classification Results: Month Anomaly Patterns | | |
|---|---|---|
| Pattern | Original | Final |
| 1 | 29 | 28 |
| 2 | 29 | 24 |
| 3 | 15 | 16 |
| 4 | 17 | 15 |
| 5 | 6 | 10 |
| 6 | 9 | 9 |
| 7 | 7 | 8 |
| 8 | 8 | 8 |
| 9 | 5 | 7 |
| 10 | 6 | 6 |



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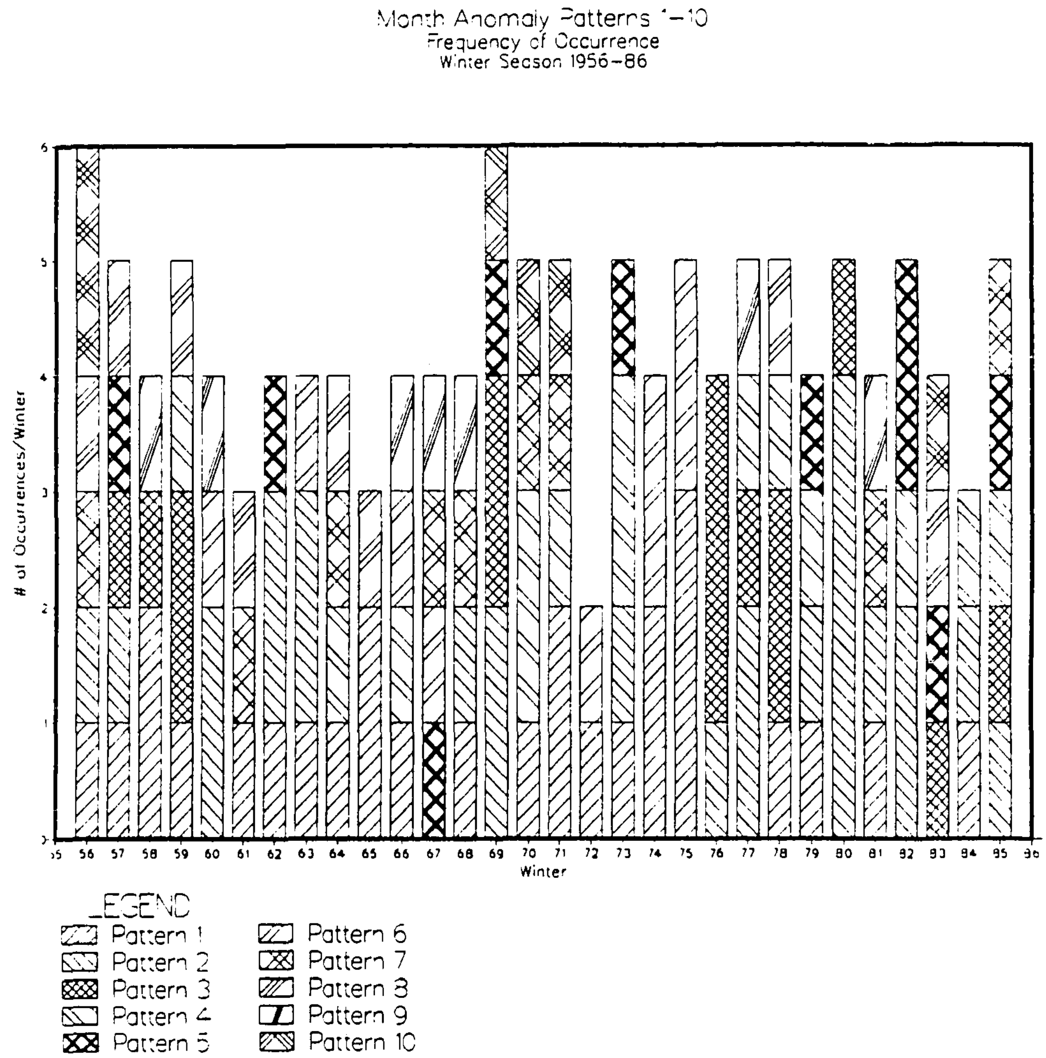


**Figure 3.9** Winter season frequency of occurrence for the ten Basic Anomaly Patterns. Winter date refers to the starting date of a winter season; there are a maximum of six anomaly patterns present in a particular season: bar length indicates how many times a pattern occurs in each winter season; missing or unclassified data is reflected in seasons with less than six *total* pattern occurrences.

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### 3.3: Results of Classification

In this section, the ten Basic Anomaly Patterns defined in the classification procedure are presented in terms of structure and frequency of occurrence statistics. A positive anomaly designated by a + sign indicates heights above the long-term mean heights for the specific region covered by the feature. A negative anomaly is defined similarly except that it is oppositely-signed.

#### 3.3.1: Pattern Description

Basic Monthly Anomaly Pattern 1 (BP1): The most dominant feature of this basic pattern (Fig. 3.10a) is a broad positive anomaly centered at $170°W, 45°N$. This feature extends north to $65°N$ and west to east from $150°E$ to $140°W$. The maximum positive value is in excess of $120m$. A smaller-scale negative anomaly is located just off the northwest U.S. coast. Its central value is approximately $-60m$. Most of Alaska is under the influence of negative height departures of $30m$. The exceptions are the Arctic coast and the Alaska Peninsula/Aleutian regions. The zero departure line crosses over the state along a diagonal extending southeast from Cape Romanzof to Kodiak Island. A second zero departure line follows the north slope of the Brooks Range. The positions of these anomaly features place Alaska under northwest/ north flow with a fairly strong gradient from Nome south to the North Pacific. This basic pattern is similar to the East Pacific pattern (Fig. 2.5) defined by Barnston and Livezey (1987).

Basic Monthly Anomaly Pattern 2 (BP2): There is only one dominant feature present on this anomaly chart (Fig. 3.10b). This is an area of negative height departure centered at $50°N, 155°W$. Its central departure value is in excess of $-150m$. The feature runs northwest to southeast from the east coast of Asia to the west coast of the contiguous United States. The steepest gradient is found in the Gulf of Alaska where departures range from $0m$ to greater than $-150m$. To the far north,

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there is a suggestion of a ridge beginning to build over the Arctic Ocean near the Alaska Canada Border. With the exception of the Southeastern region and the northeast corner, Alaska is under the influence of the negative height anomaly. Flow over the mainland sections is from the southeast. The Aleutians receive north/northeast /northwest flow. BP2 is similar to the Pacific North American (Fig. 2.4) pattern (Namias, 1975; Barnston and Livezey, 1987) as well as the patterns of Overland and Heister (Fig. 2.10c).

Basic Monthly Anomaly Pattern 3 (BP3): Pattern 3 (Fig. 3.11a) has two distinct features over the Pacific Ocean. A large area of negative height departures centered at $45° N, 170° W$ extends north to the central Bering Sea and east to west from the Alaska Peninsula to the southern tip of the Kamchatka Peninsula. Central departure value is $-90m$. The second feature is a large positive anomaly located adjacent to the east edge of the negative anomaly. It has a central value in excess of $+90m$. The third area of interest is a broad area of above average heights located over Asia and Eastern Europe. Much of Alaska is situated in a region of above normal heights, although the anomaly field over most of the state is flat. The Alaska Peninsula/ Aleutian Chain region is in the vicinity of the northern half of the negative anomaly. The north coast and the north interior of the state should receive weak northwest flow due to the above normal heights in Asia. The rest of the state will be influenced by the anomalies in the Pacific and thus, receive flow from the south or southeast . BP3 resembles sections of the Northern Asia pattern (Fig. 2.6; Barnston and Livezey, 1987) and the December version of the Pacific North American (PNA) (Fig. 2.4).

Basic Monthly Anomaly Pattern 4 (BP4): BP4 (Fig. 3.11b) has just one dominant anomaly— a large circular region of above normal heights centered over the southern Bering Sea and the tip of the Alaska Peninsula. Its central departure is in excess of $150m$. The feature extends north into the high Arctic and south to approximately $40° N$. The anomaly's east-west coverage includes the entire study area, although the strongest gradients are found over the Pacific, Bering Sea, and southwestern Alaska. As a result of the anomaly's location, the Alaskan interior is influenced by northerly flow

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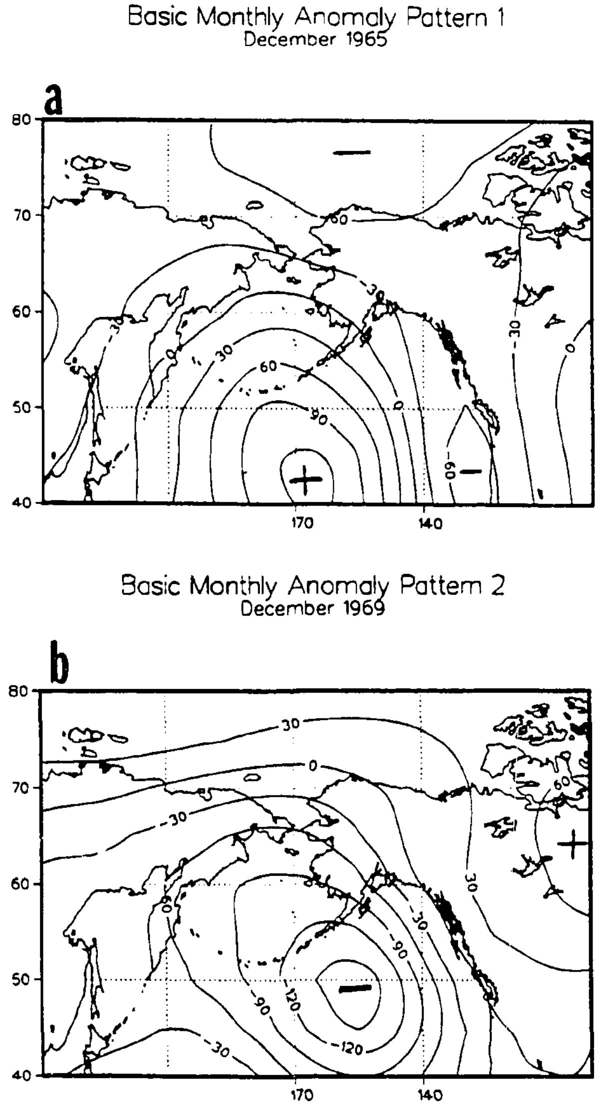


**Figure 3.10a,b** Basic Anomaly Pattern 1 (BP1) and Basic Anomaly Pattern 2 (BP2). (a) BP1,(b) BP2; the date on the patterns refers to the actual date of the basic pattern map–the Basic Anomaly Patterns are *not* an average of several different maps; units are meters, and contours are $30m$ departures from the thirty-year mean $700mb$ geopotential heights (Figs. 3.2-3.7) for the corresponding month.

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from the Arctic, and the Bering Sea coast receives flow from the west/northwest. BP4 is similar to the West Pacific Oscillation pattern, Fig. 2.7, defined by Barnston and Livezey (1987).

Basic Monthly Anomaly Pattern 5 (BP5): Pattern 5 (Fig. 3.12a) shows above normal heights over the Alaska mainland and Asia. The zero departure contour runs west to east along a diagonal from $48°N$ over Japan to $58°N$ over western Canada. South of this, over the central Pacific the departures rapidly become negative. Only the top half of the negative anomaly feature is located in the study area but the north/south gradient across the Pacific from $55°N$ to $40°N$ is in excess of $-180m$. With the exception of the Aleutian region, Alaska is in an area of weak westward or eastward flow tendencies. From the Alaska Peninsula south, flow is westerly and fairly intense. The flow near the Canadian border is southerly. This basic pattern resembles the patterns (Fig. 2.9a-c) defined by Yamal (1985)

Basic Monthly Anomaly Pattern 6 (BP6): Pattern 6 (Fig. 3.12b) shows a tongue of slightly below normal heights extending northeast to southwest across Alaska and the Central Pacific. An area of above average heights centered off the map at $140°W$ is present along the west coast of Washington. Although a time series has not been investigated, the position of the positive anomaly suggests that this feature is related to ridge formation over the western region of North America. Flow over Alaska is weak and either northeasterly or southwesterly depending on locale. This pattern is somewhat similar to the March and December Northern Asia pattern shown in Fig. 2.6 (Barnston and Livezey, 1987).

Basic Monthly Anomaly Pattern 7 (BP7): The main feature of this pattern (Fig. 3.13a) is a positive anomaly centered over the north Pacific near $45°N$, $160°W$. It extends diagonally northwest from its center position towards Asia. Most of the feature is located over the ocean just south of the Aleutian Chain. The north/northeast sector of the anomaly encloses much of western Alaska. The central and eastern sections of Alaska are in an area of zero to slightly negative departures. A weak area of below normal heights is situated over western Canada and southeast Alaska. The strongest

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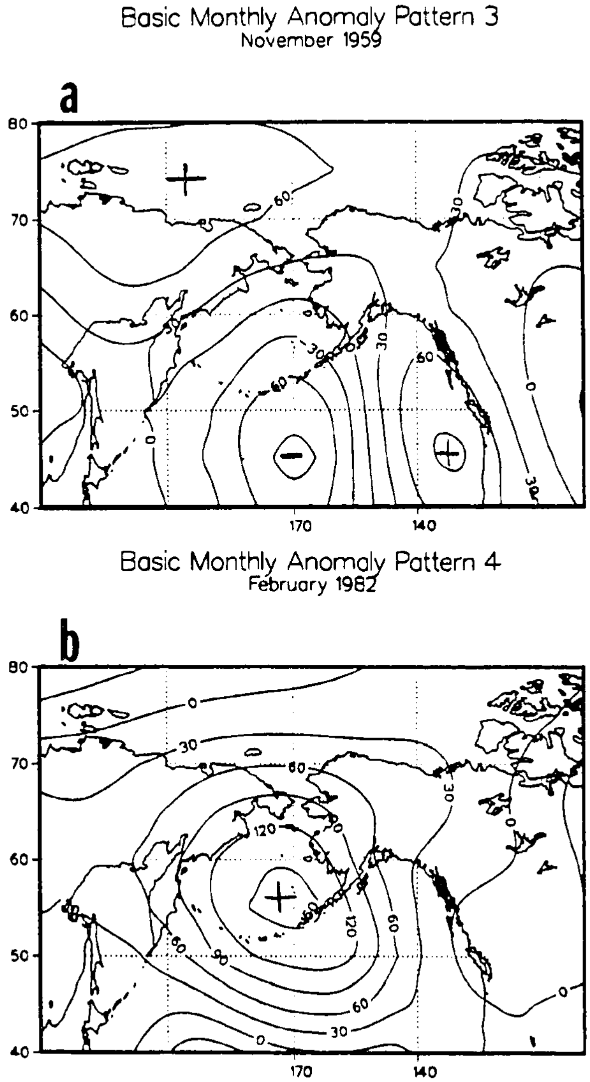


**Figure 3.11a,b** Basic Monthly Anomaly Pattern 3 (BP3) and Basic Anomaly Pattern 4 (BP4). (a) BP3, (b) BP4; as in Fig. 3.10a,b.

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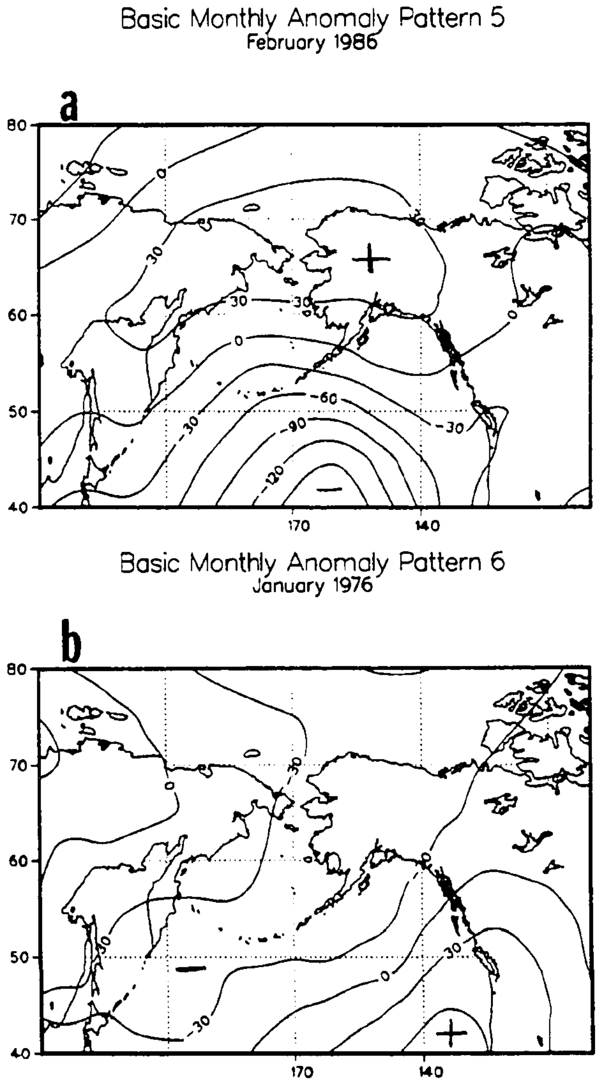


**Figure 3.12a,b** Basic Monthly Anomaly Pattern 5 (BP5) and Basic Anomaly Pattern 6 (BP6). (a) BP5, (b) BP6; as in Fig. 3.10a,b.

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gradient of the pattern runs northeast across the Gulf of Alaska with departure values ranging from $+90m$ to $-30m$. BP7 shows a resemblence to the West Pacific Oscillation pattern (Fig. 2.7) defined by Barnston and Livezey, 1987; Wallace and Gutzler, 1981).

Basic Monthly Anomaly Pattern 8 (BP8): There are three main features of interest on this map (Fig. 3.13b). One is a broad area of negative departures centered at $160°E, 60°N$. The maximum departure is $-60m$. The second feature is an area of above normal heights centered over Kodiak Island. This feature extends north from the North Pacific Ocean to the Arctic Ocean and east from Siberia into central Canada. The central departure value is greater than $+120m$. The third feature is an area of below normal heights extending in a northeast direction over Washington. The steepest gradients are located along the intersections of the three features. The strong gradients are located over the Bering Sea, and over the eastern Gulf of Alaska. Alaska appears to be most influenced by the large positive anomaly feature. The Southeast region of the state is in an area of NE flow. The flow over the southern Gulf of Alaska is predominantly easterly. The Alaska Peninsula and Aleutians are in the belt of southerly flow, while the Interior Basin experiences west to northwest flow. This basic pattern is most similar to the East Pacific pattern (Dole and Gordon, 1983; Barnston and Livezey, 1987) shown in Fig. 2.5.

Basic Monthly Anomaly Pattern 9 (BP9): Pattern 9 (Fig. 3.14a) is suggestive of a more high Arctic-oriented situation. The area south of $60°N$ is slightly above normal to the west of $170°W$ and slightly below normal to the east. North of $60°N$ there are two anomaly features. One is a large area of below normal heights (central value in excess of $-90m$) centered over the North coast of Eastern Europe. This anomaly extends east over Alaska although its most intense structure weakens as it reaches the Bering Sea region. The second high latitude feature is an area of above normal heights extending south from the Arctic across the northern most regions of Canada. Its central value is in excess of $60m$. Alaska is located directly between these two anomalies within an area of slightly below normal heights. The circulation pattern set up by the anomaly features suggests

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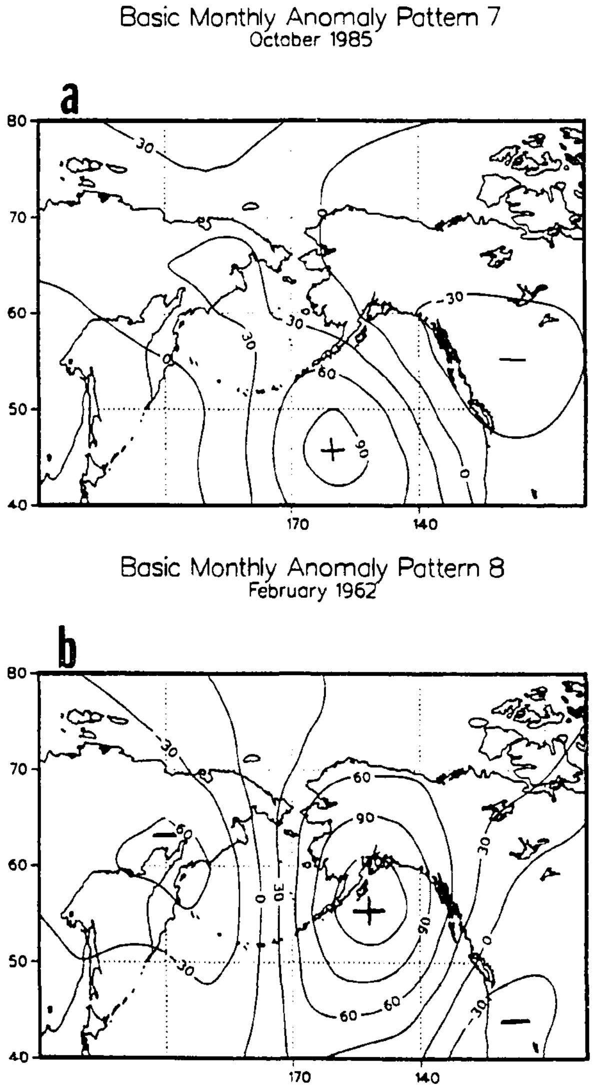


**Figure 3.13a,b** Basic Monthly Anomaly Pattern 7 (BP7) and Basic Anomaly Pattern 8 (BP8). (a) BP7, (b) BP8; as in Fig. 3.10a,b.

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predominantly southeasterly flow across the eastern and interior sectors of the state. The Bristol Bay and Aleutian region are most influenced by the Eurasian negative anomaly and thus would be in a belt of weak southwesterly winds. This basic pattern is similar to the Northern Asia pattern (Fig. 2.6) when the Northern Asia pattern (Barnston and Livezey, 1987) is characterized by a large negative anomaly feature centered over Eurasia.

Basic Monthly Anomaly Pattern 10 (BP 10): There are four areas of interest in this basic pattern (Fig. 3.14b). The first is a large positive anomaly that appears to dominate the western third of the map. It extends from $40° N, 180° W$ northward beyond $80° N$ and west well past $130° W$. The feature is oriented on a slight tilt running NW to SE. Its central anomaly value is greater than $+180m$. The second feature of interest is the broad region of negative heights centered over Northwest Alaska, and Western Canada. The maximum departure in this feature is $> -60m$. There is a fairly strong gradient apparent over Asia between this negative anomaly feature and the large positive anomaly to the west. The third element of the pattern is an area of above average heights off the west coast of Washington and British Columbia. This anomaly feature extends northward to southeast Alaska and west to approximately $155° W$. Its maximum value is in excess of $+60m$. The last feature is a rather small area of below normal heights separating the southernmost section of the large positive anomaly over Asia and the positive anomaly off the coast of Washington. It is located at $170° W, 40° - 48° N$ and it has a departure value of $-30m$. Alaska is under the influence of below normal heights everywhere except in the Southeast region. This pattern has characteristics similar to the February West Pacific Oscillation (Barnston and Livezey, 1987) pattern shown in Fig. 2.7.

### 3.3.2: Occurrence Statistics

Before presenting these statistics, certain terms appearing on the associated figures and tables must be defined. "Prior" and "future" pattern statistics are shown in Tables 3.2a,b-3.11a,b. An intraseasonal

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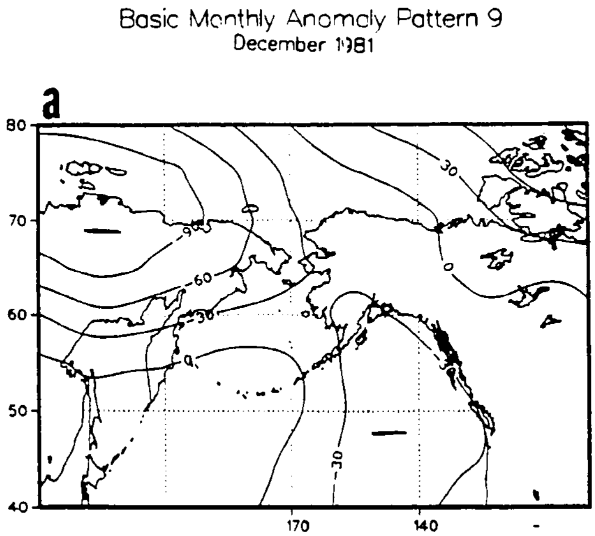


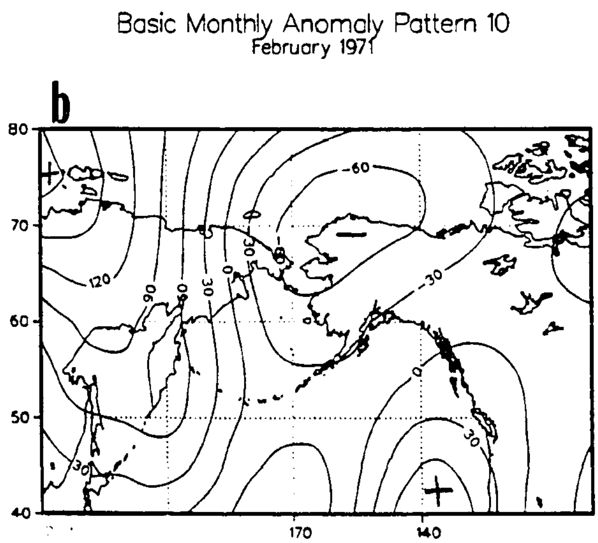


**Figure 3.14a,b** Basic Monthly Anomaly Pattern 9 (BP9) and Basic Anomaly Pattern 10 (BP10). (a) BP9, (b) BP10; as in Fig. 3.10a,b.

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"prior" pattern is one that characterizes the month (same season) immediately prior to the pattern being discussed. An intraseasonal "future" pattern is one that occurs during the month (same season) immediately following the pattern being discussed. An interseasonal "prior"/ "future" pattern is one that occurs during the same month, but one season prior to/after the pattern being discussed. Statistics are shown as actual number of occurrences and in percentage form for the thirty year study period. Unclassified months have not been included in these statistics. Each basic anomaly pattern is now discussed individually as before.

BP1: BP 1 is the most frequently occurring monthly-scale anomaly pattern in our study period. The basic anomaly pattern map is from December 1965. There were 28 other maps considered to be similar to it. Correlation coefficients between this pattern and other similar patterns ranged from .844 to .611 resulting in an average correlation coefficient of .697. The pattern occurs consistently throughout the study period ( Fig. 3.15a) until 1976. After 1976, the pattern only occurs four times. The pattern is also well-distributed throughout the winter season as there does not appear to be a preferential month in the set of similar maps.

Intraseason statistics (Table 3.2a) show that BP 1 is most often seen after BP4 or BP6. BP9 and BP10 never precede BP1. BP4 is the most common "future" pattern. Interseason statistics (Table 3.2b) indicate that the most prevalent "prior" and "future" BP is BP1. This suggests some type of persistence possibly driven by larger-scale atmospheric activity. Once the BP1 feature is established for a month, it tends to return to that pattern from winter season to winter season.

BP2: This anomaly pattern is the second most common anomaly pattern found in the study period. The basic chart is from December 1969. There are 24 maps similar to it. Correlation coefficients between similar maps range from .892 to .610 resulting in an average value of .727. The pattern frequency appears to be a pseudo-bimodal distribution (Fig. 3.15b). Fifty percent of its occurrences are prior to 1971, and the other 50% follow after 1971. The pattern is most frequent in the 1980 winter season when its existence is suggested for four of the six months. The pattern

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frequency is most concentrated from 1976 to 1982. The pattern is least frequent in February, but it is primarily scattered throughout the months for any given winter season. The most frequent intraseason (Table 3.3a) "prior" patterns are BP2, BP3, BP4. The most common "future" pattern is BP5. BP1 and BP3 are the most common interseason (Table 3.3b) "prior" patterns. BP1 and BP2 are the most likely "future" patterns.

BP3: This pattern is ranked third in terms of frequency of occurrence. There are 16 maps considered similar to it. The basic pattern map is from November 1959. Correlation coefficients between this pattern and those similar to it range from .619 to .833 with an average value of .727. From Fig. 3.16a, it can be seen that this type of pattern was almost non-existent from 1960 to 1975. Although the pattern is most frequent in the late 1970's and early 1980's, it also occurred in the late 1950's. According to our results, the pattern does not occur in February and it only developed once in November. It is most prevalent in December and January.

The most common intraseason (Table 3.4a) "prior"/ "future" pattern(s) is/are BP2/ BP1, BP2, BP3. On the interseasonal time scale (Table 3.4b), BP1 occurs most often as a "prior" pattern and BP2 is the most common "future" pattern.

BP4: BP4, the fourth most common, occurs 15 times during the 30 year study period. The basic pattern chart is based on February 1982. Correlation coefficients calculated between the basic pattern and maps determined to be similar range from a low of .608 to a high of .852. The average value is .681. BP4 appears to be most frequent (Fig 3.16b) during the seasons after 1969. It occurs in all but six winter seasons between 1970/71 and 1985/86, inclusive. Over the 30 year period, November is the most common month for the pattern to exist. However, there is a concentration of February episodes in the 1980's. Intraseason lag/lead patterns are BP1 and BP7 (Table 3.5a). Interseason lag/lead patterns are BP8, BP9, BP1, and BP6 (Table 3.5b).

BP5: BP5 has 10 maps similar to it. The basic pattern is based on the February 1986 month anomaly chart. Correlation coefficient values between the basic map and those similar to it range

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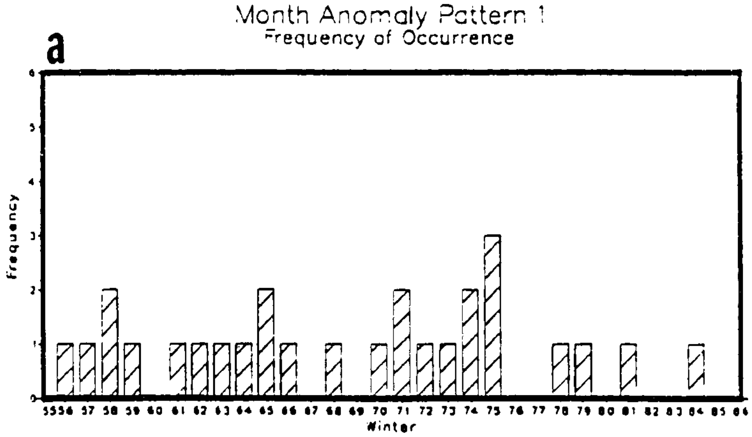


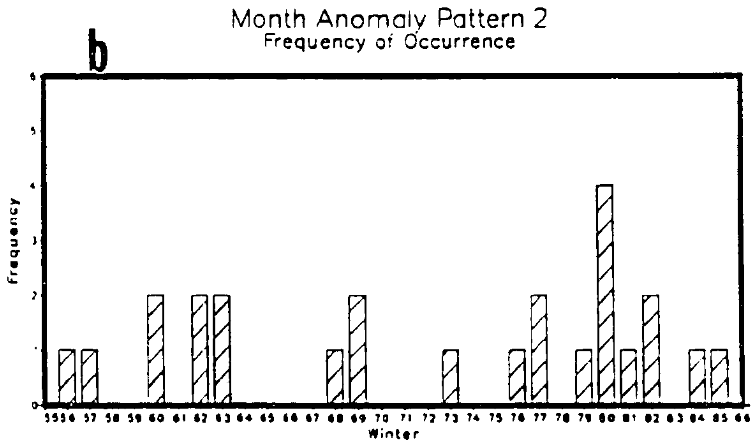


**Figure 3.15a,b** Frequency of occurrence distribution for Basic Anomaly Pattern 1 (BP1) and Basic Anomaly Pattern 2 (BP2). (a) BP1, (b) BP2; frequency refers to the number of occurrences of the Basic Anomaly Pattern during each of the winter seasons from 1956/57 to 1985/86 (winter date is start date of season).

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**Table 3.2a,b** Sequential Occurrence Frequency 1956/57 to 1985/86- Basic Anomaly Pattern 1 (BP1). (a) Intraseason prior/ future Basic Anomaly Patterns, (b) Interseason prior/ future Basic Anomaly Patterns; Intraseason refers to occurrences for the month immediately following (future) or immediately preceding (prior) BP1 in the same season; Interseason refers to occurrences for the same month as BP1, but during the immediately preceding (prior) season or during the season that immediately follows (future) the season in question; numbers indicate sequence frequency over the 30 years, percentages indicate percent frequency.

**a**

| Pattern 1: Sequential Occurrence Frequency Intraseason 1956-86 | | |
|---|---|---|
| Pattern | Prior | Future |
| 1 | 2 (12%) | 2 (15%) |
| 2 | 2 (12) | 1 (8) |
| 3 | 2 (12) | 0 |
| 4 | 4 (24) | 3 (23) |
| 5 | 1 (6) | 0 |
| 6 | 4 (24) | 2 (15) |
| 7 | 1 (6) | 2 (15) |
| 8 | 1 (6) | 1 (8) |
| 9 | 0 | 1 (8) |
| 10 | 0 | 1 (8) |

**b**

| Pattern 1: Sequential Occurrence Frequency Interseason 1956-86 | | |
|---|---|---|
| Pattern | Prior | Future |
| 1 | 5 (25%) | 5 (28%) |
| 2 | 3 (15) | 4 (22) |
| 3 | 2 (10) | 3 (17) |
| 4 | 4 (20) | 1 (6) |
| 5 | 1 (5) | 0 |
| 6 | 1 (5) | 2 (11) |
| 7 | 3 (15) | 0 |
| 8 | 0 | 2 (11) |
| 9 | 0 | 1 (6) |
| 10 | 1 (5) | 0 |

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**Table 3.3a,b** Sequential Occurrence Frequency 1956/57 to 1985/86- Basic Anomaly Pattern 2 (BP2). (a) Intraseason prior/ future Basic Anomaly Patterns, (b) Interseason prior/ future Basic Anomaly Patterns; as in Table 3.2a,b.

**a**

Pattern 2:
Sequential Occurrence Frequency
Intraseason 1956-86

| Pattern | Prior | Future |
|---|---|---|
| 1 | 1 (9%) | 2 (13%) |
| 2 | 2 (18) | 3 (20) |
| 3 | 2 (18) | 3 (20) |
| 4 | 2 (18) | 1 (7) |
| 5 | 1 (9) | 4 (27) |
| 6 | 0 | 1 (7) |
| 7 | 1 (9) | 0 |
| 8 | 0 | 0 |
| 9 | 1 (9) | 1 (7) |
| 10 | 1 (9) | 0 |

**b**

Pattern 2:
Sequential Occurrence Frequency
Interseason 1956-86

| Pattern | Prior | Future |
|---|---|---|
| 1 | 4 (24%) | 3 (19%) |
| 2 | 3 (18) | 3 (19) |
| 3 | 4 (24) | 2 (13) |
| 4 | 1 (6) | 0 |
| 5 | 0 | 0 |
| 6 | 1 (6) | 1 (6) |
| 7 | 1 (6) | 1 (6) |
| 8 | 1 (6) | 3 (19) |
| 9 | 1 (6) | 1 (6) |
| 10 | 1 (6) | 2 (13) |

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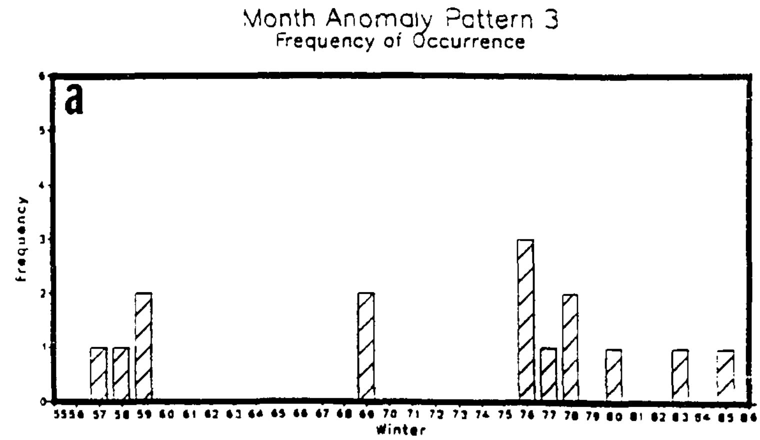


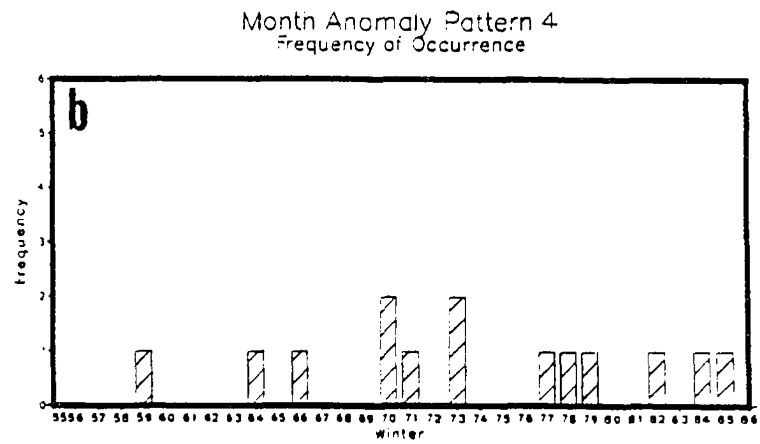


**Figure 3.16a,b** Frequency of occurrence distribution for Basic Anomaly Pattern 3 (BP3) and Basic Anomaly Pattern 4 (BP4). (a) BP3, (b) BP4; frequency refers to the number of occurrences of the Basic Anomaly Pattern during each of the winter seasons from 1956/57 to 1985/86 (winter date is start date of season).

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**Table 3.4a,b** Sequential Occurrence Frequency 1956/57 to 1985/86- Basic Anomaly Pattern 3 (BP3). (a) Intraseason prior/ future Basic Anomaly Patterns, (b) Interseason prior/ future Basic Anomaly Patterns; as in Table 3.2a,b.

**a** Pattern 3: Sequential Occurrence Frequency Intraseason 1956-86

| Pattern | Prior | Future |
|---|---|---|
| 1 | 0 | 2 (33%) |
| 2 | 3 (75%) | 2 (33) |
| 3 | 0 | 2 (33) |
| 4 | 0 | 0 |
| 5 | 0 | 0 |
| 6 | 0 | 0 |
| 7 | 0 | 0 |
| 8 | 0 | 0 |
| 9 | 1 (25) | 0 |
| 10 | 0 | 0 |

**b** Pattern 3: Sequential Occurrence Frequency Interseason 1956-86

| Pattern | Prior | Future |
|---|---|---|
| 1 | 4 (36%) | 2 (20%) |
| 2 | 2 (18) | 4 (40) |
| 3 | 0 | 1 (10) |
| 4 | 0 | 2 (20) |
| 5 | 0 | 0 |
| 6 | 2 (18) | 0 |
| 7 | 1 (9) | 0 |
| 8 | 0 | 0 |
| 9 | 1 (9) | 1 (10) |
| 10 | 1 (9) | 0 |

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**Table 3.5a,b** Sequential Occurrence Frequency 1956/57 to 1985/86- Basic Anomaly Pattern 4 (BP4). (a) Intraseason prior/ future Basic Anomaly Patterns, (b) Interseason prior/ future Basic Anomaly Patterns; as in Table 3.2a,b.

**a**

| Pattern 4: Sequential Occurrence Frequency Intraseason 1956-86 | | |
|---|---|---|
| Pattern | Prior | Future |
| 1 | 2 (22%) | 4 (36%) |
| 2 | 2 (22) | 2 (18) |
| 3 | 0 | 2 (18) |
| 4 | 0 | 1 (9) |
| 5 | 0 | 1 (9) |
| 6 | 0 | 0 |
| 7 | 3 (33) | 0 |
| 8 | 2 (22) | 0 |
| 9 | 0 | 0 |
| 10 | 0 | 1 (9) |

**b**

| Pattern 4: Sequential Occurrence Frequency Interseason 1956-86 | | |
|---|---|---|
| Pattern | Prior | Future |
| 1 | 1 (14%) | 2 (25%) |
| 2 | 0 | 1 (12.5) |
| 3 | 1 (14) | 0 |
| 4 | 0 | 0 |
| 5 | 0 | 1 (12.5) |
| 6 | 0 | 2 (25) |
| 7 | 0 | 0 |
| 8 | 2 (29) | 1 (12.5) |
| 9 | 1 (14) | 1 (12.5) |
| 10 | 2 (29) | 0 |

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from .602 to .728 resulting in an average of .677. As shown in Fig. 3.17a, BP5 tends to occur in 6+ year intervals through 1979. After 1979, the pattern occurs more frequently and with a shorter periodicity. The pattern is predominantly a February pattern. It does not seem to occur in December. Furthermore, until 1969, it did not occur in any month except February. BP5 is most often preceded by BP3 and followed by BP8 on an intraseasonal scale (Table 3.6a). On the interannual scale (Table 3.6b), BP4 is the most dominant "prior" pattern. BP1, BP1, BP6, and BP7 appear with equal frequency as "future" patterns.

BP6: BP6 is based on the January 1976 anomaly chart. It has six month anomaly maps similar to it. Correlation coefficients range from .607 to .797 with the average value being .712. BP6 (Fig. 3.17b) is only found in the 1960's and the early 1970's. The pattern occurs four times over the period from 1974/75 to 1975/76. During the 1970's, the pattern favors December, January, and November. Finally, BP6 does not occur in October and it does not occur after 1976. "Future" patterns (Tables 3.7a,b) include BP4 (intraseason) and BP3 (interseason) . "Prior" patterns (Tables 3.7a,b) include BP1 and BP6 (intraseason) as well as BP1 and BP4 (interseason).

BP7: There are eight maps similar to the basic pattern. The basic pattern is based on the anomaly chart from October 1985. Correlation coefficients between the basic map and those similar range from .604 to .776. The average value is .693. BP7 (Fig. 3.18a) only occurs in January, October, and March. It is concentrated throughout the 1967-1971 winter seasons. Outside of that period, the pattern occurs at intervals ranging from 9 to 15 years. Dominant intraseason "prior"/ "future" patterns (Table 3.8a) include BP1 and BP4. There is no dominant "prior" interseason pattern (Table 3.8b) for BP7 as seven out of ten basic patterns appear at least once in the record. The most common "future" pattern is BP1. The lag/lead characteristics for BP7 are influenced by the fact that the pattern seemed to occur most often in seasons where a large number of initial grids were missing. While the month that is designated a BP7 month was always complete, the months preceding and following might have been discarded in the initial classification process due to their lack of data.

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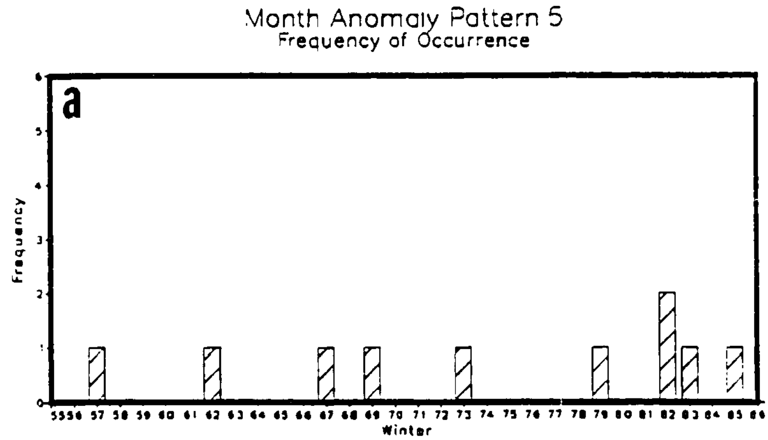


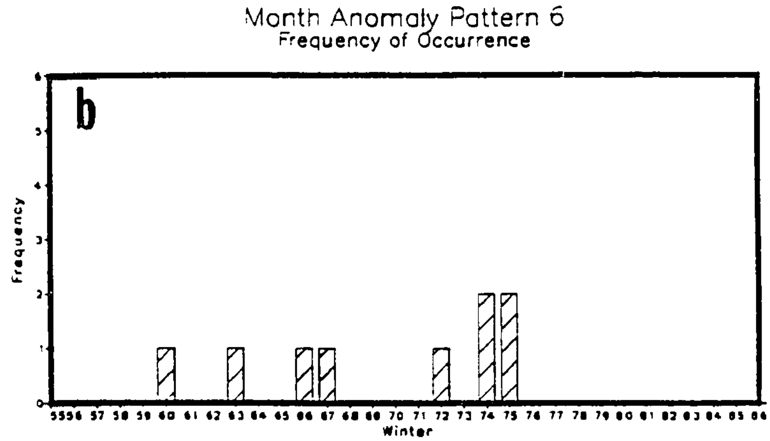


**Figure 3.17a,b** Frequency of occurrence distribution for Basic Anomaly Pattern 5 (BP5) and Basic Anomaly Pattern 6 (BP6). (a) BP5, (b) BP6; frequency refers to the number of occurrences of the Basic Anomaly Pattern during each of the winter seasons from 1956/57 to 1985/86 (winter date is start date of season).

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**Table 3.6a,b** Sequential Occurrence Frequency 1956/57 to 1985/86- Basic Anomaly Pattern 5 (BP5). (a) Intraseason prior/ future Basic Anomaly Patterns, (b) Interseason prior/ future Basic Anomaly Patterns; as in Table 3.2a,b.

**a** Pattern 5: Sequential Occurrence Frequency Intraseason 1956-86

| Pattern | Prior | Future |
|---|---|---|
| 1 | 0 | 1 (12.5%) |
| 2 | 3 (50%) | 1 (12.5) |
| 3 | 0 | 0 |
| 4 | 1 (17) | 0 |
| 5 | 1 (17) | 1 (12.5) |
| 6 | 0 | 0 |
| 7 | 1 (17) | 0 |
| 8 | 0 | 2 (25) |
| 9 | 0 | 1 (12.5) |
| 10 | 0 | 1 (12.5) |

**b** Pattern 5: Sequential Occurrence Frequency Interseason 1956-86

| Pattern | Prior | Future |
|---|---|---|
| 1 | 0 | 1 (25%) |
| 2 | 0 | 0 |
| 3 | 0 | 0 |
| 4 | 3 (38%) | 0 |
| 5 | 0 | 0 |
| 6 | 2 (25) | 1 (25) |
| 7 | 1 (12.5) | 1 (25) |
| 8 | 1 (12.5) | 0 |
| 9 | 1 (12.5) | 0 |
| 10 | 0 | 1 (12.5) |

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**Table 3.7a,b** Sequential Occurrence Frequency 1956/57 to 1985/86- Basic Anomaly Pattern 6 (BP6). (a) Intraseason prior/ future Basic Anomaly Patterns, (b) Interseason prior/ future Basic Anomaly Patterns; as in Table 3.2a,b.

**a**

| Pattern 6: Sequential Occurrence Frequency Intraseason 1956-86 | | |
|---|---|---|
| Pattern | Prior | Future |
| 1 | 2 (29%) | 4 (57%) |
| 2 | 1 (14) | 0 |
| 3 | 1 (14) | 0 |
| 4 | 0 | 0 |
| 5 | 0 | 0 |
| 6 | 2 (29) | 2 (29) |
| 7 | 0 | 0 |
| 8 | 0 | 0 |
| 9 | 1 (14) | 1 (14) |
| 10 | 0 | 0 |

**b**

| Pattern 6: Sequential Occurrence Frequency Interseason 1956-86 | | |
|---|---|---|
| Pattern | Prior | Future |
| 1 | 2 (29%) | 1 (12.5%) |
| 2 | 1 (14) | 1 (12.5) |
| 3 | 0 | 2 (25) |
| 4 | 2 (29) | 0 |
| 5 | 0 | 1 (12.5) |
| 6 | 1 (14) | 1 (12.5) |
| 7 | 0 | 0 |
| 8 | 1 (14) | 1 (12.5) |
| 9 | 0 | 1 (12.5) |
| 10 | 0 | 0 |

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BP8: This pattern is the eighth most frequent pattern in the study period. There are eight other maps similar to it. The basic pattern map is from February 1962. Correlation coefficients between the basic pattern map and those similar to it range from .759 to .631 with the average being .686. BP8 only occurs twice after 1965– once in 1978 and once in 1983. The anomaly never occurs in October and it only occurs once in November and December. This suggests that it is a late winter feature. Furthermore, from Fig. 3.18b, it can be seen that the pattern only occurs in years associated with the El Nino-Southern Oscillation negative index phenomena (Niebauer, 1988; Namias, 1981). BP5 is the pattern most likely to occur prior to BP8 on an intraseasonal basis and BP4 is most likely to succeed it (Table 3.9a). On an interseasonal time scale, BP2 is the most prominent "prior" pattern and BP4 is again the most common succeeding pattern (Table 3.9b).

BP9: BP9 is based on the December 1982 anomaly map. There are 7 maps similar to it. The average correlation coefficient between the basic pattern and similar maps is .688. The highest value is .747 and the lowest is .603. BP9 occurs (Fig. 3.19a) most frequently in March, although it is found at least once in the other winter months. It is scattered throughout the study period. Three patterns—BP1, BP2, and BP6— share the distinction of occuring prior to BP9 on an intraseasonal (Table 3.10a) basis. BP2 and BP3 combine to make up 80% of the "future" patterns. The most common interseason (Table 3.10b) "prior" is BP3. There is no dominant "future" pattern.

BP10: This pattern has been determined to be the least frequent. There are only six maps similar to it. The basic pattern is from February 1971. Correlation coefficients range from .613 to .711 for an average value of .649. BP10 events appear to be concentrated from 1969 to 1971 (Fig. 3.19b). The pattern did not occur in October. It also appears to occur in 15 year intervals. Pattern is most often preceded by BP4 on an intraseasonal scale. There is no dominant "future" pattern (Table 3.11a). On an interseasonal basis (Table 3.11b), "prior" patterns include BP2 and BP5. The most prevalent "future" pattern is BP4.

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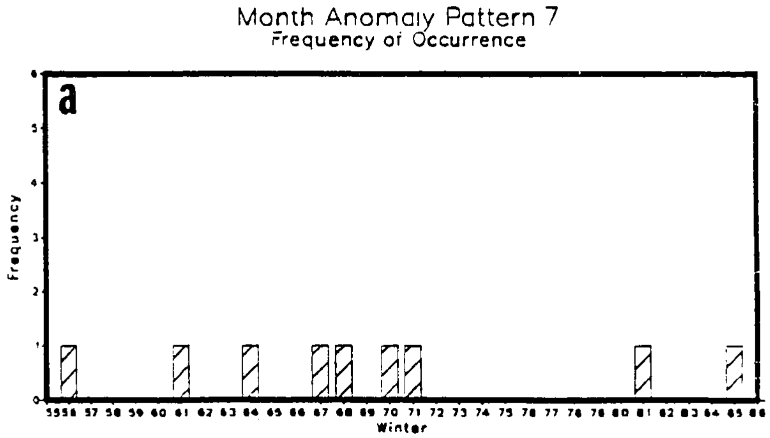


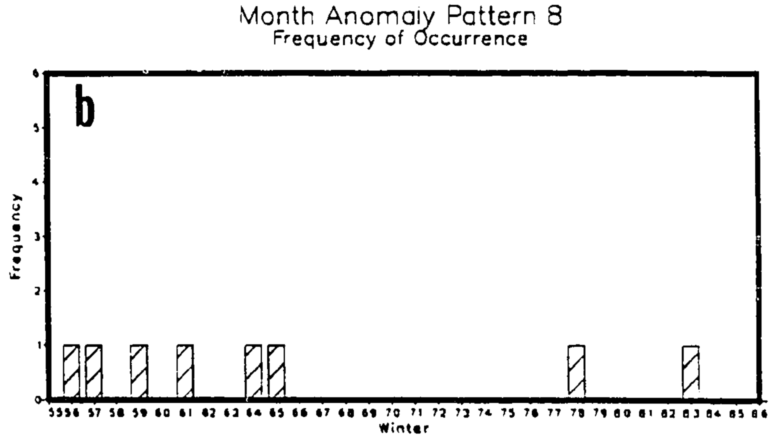


**Figure 3.18a,b** Frequency of occurrence distribution for Basic Anomaly Pattern 7 (BP7) and Basic Anomaly Pattern 8 (BP8). (a) BP7, (b) BP8; frequency refers to the number of occurrences of the Basic Anomaly Pattern during each of the winter seasons from 1956/57 to 1985/86 (winter date is start date of season).

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**Table 3.8a,b** Sequential Occurrence Frequency 1956/57 to 1985/86- Basic Anomaly Pattern 7 (BP7). (a) Intraseason prior/ future Basic Anomaly Patterns, (b) Interseason prior/ future Basic Anomaly Patterns; as in Table 3.2a,b.

**a**

Pattern 7:
Sequential Occurrence Frequency
Intraseason 1956-86

| Pattern | Prior | Future |
|---|---|---|
| 1 | 2 (66%) | 1 (14%) |
| 2 | 0 | 1 (14) |
| 3 | 0 | 0 |
| 4 | 0 | 3 (43) |
| 5 | 0 | 1 (14) |
| 6 | 0 | 0 |
| 7 | 0 | 0 |
| 8 | 1 (33) | 1 (14) |
| 9 | 0 | 0 |
| 10 | 0 | 0 |

**b**

Pattern 7:
Sequential Occurrence Frequency
Interseason 1956-86

| Pattern | Prior | Future |
|---|---|---|
| 1 | 0 | 3 (43%) |
| 2 | 1 (14%) | 1 (14) |
| 3 | 0 | 1 (14) |
| 4 | 1 (14) | 0 |
| 5 | 1 (14) | 1 (14) |
| 6 | 1 (14) | 0 |
| 7 | 1 (14) | 1 (14) |
| 8 | 0 | 0 |
| 9 | 1 (14) | 0 |
| 10 | 1 (14) | 0 |

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**Table 3.9a,b** Sequential Occurrence Frequency 1956/57 to 1985/86- Basic Anomaly Pattern 8 (BP8). (a) Intraseason prior/ future Basic Anomaly Patterns, (b) Interseason prior/ future Basic Anomaly Patterns; as in Table 3.2a,b.

**a** Pattern 8: Sequential Occurrence Frequency Intraseason 1956-86

| Pattern | Prior | Future |
|---|---|---|
| 1 | 1 (20%) | 1 (20%) |
| 2 | 0 | 0 |
| 3 | 0 | 0 |
| 4 | 0 | 2 (40) |
| 5 | 2 (40) | 0 |
| 6 | 0 | 0 |
| 7 | 1 (20) | 1 (20) |
| 8 | 0 | 0 |
| 9 | 0 | 0 |
| 10 | 1 (20) | 1 (20) |

**b** Pattern 8: Sequential Occurrence Frequency Interseason 1956-86

| Pattern | Prior | Future |
|---|---|---|
| 1 | 1 (17%) | 0 |
| 2 | 3 (50) | 1 (25%) |
| 3 | 0 | 0 |
| 4 | 1 (17) | 2 (50) |
| 5 | 0 | 1 (25) |
| 6 | 1 (17) | 0 |
| 7 | 0 | 0 |
| 8 | 0 | 0 |
| 9 | 0 | 0 |
| 10 | 0 | 0 |

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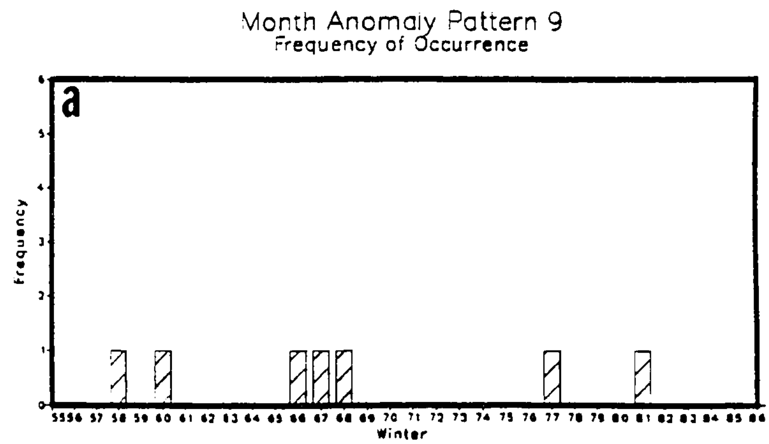


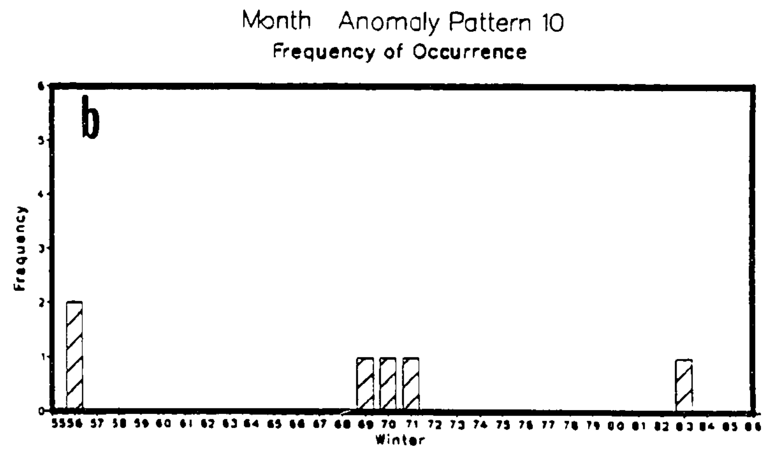


**Figure 3.19a,b** Frequency of occurrence distribution for Basic Anomaly Pattern 9 (BP9) and Basic Anomaly Pattern 10 (BP10). (a) BP9, (b) BP10; frequency refers to the number of occurrences of the Basic Anomaly Pattern during each of the winter seasons from 1956/57 to 1985/86 (winter date is start date of season).

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**Table 3.10a,b** Sequential Occurrence Frequency 1956/57 to 1985/86- Basic Anomaly Pattern 9 (BP9). (a) Intraseason prior/ future Basic Anomaly Patterns, (b) Interseason prior/ future Basic Anomaly Patterns; as in Table 3.2a,b.

**a**

Pattern 9:
Sequential Occurrence Frequency
Intraseason 1956-86

| Pattern | Prior | Future |
|---|---|---|
| 1 | 1 (33%) | 0 |
| 2 | 1 (33) | 2 (40%) |
| 3 | 0 | 2 (40) |
| 4 | 0 | 0 |
| 5 | 0 | 0 |
| 6 | 1 (33) | 1 (20) |
| 7 | 0 | 0 |
| 8 | 0 | 0 |
| 9 | 0 | 0 |
| 10 | 0 | 0 |

**b**

Pattern 9:
Sequential Occurrence Frequency
Interseason 1956-86

| Pattern | Prior | Future |
|---|---|---|
| 1 | 1 (20%) | 0 |
| 2 | 1 (20) | 1 (20%) |
| 3 | 2 (40) | 1 (20) |
| 4 | 1 (20) | 1 (20) |
| 5 | 0 | 1 (20) |
| 6 | 0 | 0 |
| 7 | 0 | 1 (20) |
| 8 | 0 | 0 |
| 9 | 0 | 0 |
| 10 | 0 | 0 |

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**Table 3.11a,b** Sequential Occurrence Frequency 1956/57 to 1985/86- Basic Anomaly Pattern 10 (BP10). (a) Intraseason prior/ future Basic Anomaly Patterns, (b) Interseason prior/ future Basic Anomaly Patterns; as in Table 3.2a,b.

**a**

| Pattern 10: Sequential Occurrence Frequency Intraseason 1956-86 | | |
|---|---|---|
| Pattern | Prior | Future |
| 1 | 1 (17%) | 0 |
| 2 | 0 | 1 (33%) |
| 3 | 0 | 0 |
| 4 | 2 (33) | 0 |
| 5 | 1 (17) | 0 |
| 6 | 0 | 0 |
| 7 | 0 | 0 |
| 8 | 1 (17) | 1 (33) |
| 9 | 0 | 0 |
| 10 | 1 (17) | 1 (33) |

**b**

| Pattern 10: Sequential Occurrence Frequency Interseason 1956-86 | | |
|---|---|---|
| Pattern | Prior | Future |
| 1 | 0 | 1 |
| 2 | 2 (66%) | 1 (17%) |
| 3 | 0 | 1 (17) |
| 4 | 0 | 2 (33) |
| 5 | 1 (33) | 0 |
| 6 | 0 | 1 (17) |
| 7 | 0 | 0 |
| 8 | 0 | 0 |
| 9 | 0 | 0 |
| 10 | 0 | 0 |

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### 3.4: Summary

An adapted Kirchhofer (1973)/ Lund(1963) classification scheme has been used to define ten $700mb$ Basic Anomaly Patterns. These patterns were then used to categorize the individual month-scale anomaly patterns. A total of 78% of the monthly $700mb$ anomaly patterns present in the study region during the Alaska winter seasons of 1956-86 were successfully classified into these ten categories. The most common pattern, BP1, is characterized by a large positive anomaly centered over the ocean just south of the Aleutian Islands. The second most common anomaly pattern shows the well-documented Aleutian Low centered over the western Gulf of Alaska. The least common anomaly pattern (BP10) has a large negative anomaly over Alaska.

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## Chapter 4: Surface Climatology

By definition, the second element of a synoptic climatology is an investigation of a region's surface climatology. Again, focus is placed on the dynamic winter season climate of Alaska. A region's climate may be defined by a time series of different meteorological phenomenon either as individual components, or in conjunction with other elements (Barry and Perry, 1973). Surface climate components may include observational records of precipitation, temperature, cloud cover, wind speed/direction, humidity, and solar radiation. In this study, only the basic elements of observed mean surface air temperature (mst) and precipitation (msp) of the six month winter season are to be discussed here.

In order to examine the winter season climate, it was necessary to first define the period of interest. Winter-like weather may occur at any point during the year in Alaska. Snow may fall as early as the beginning of August and as late as the end of July at higher altitudes and along the Arctic coast. The end of winter as signaled by "Spring Break-up" may be as early as mid-February in the southern reaches (Ketchikan) of the state and as late as July in other regions (high elevations and North Slope).

From a review of the pertinent literature, it is noted that the major research (Dole and Gordon, 1983; Hsu and Wallace, 1985; Barnston and Livezey, 1987) concerning Northern Hemisphere winter climate have defined the winter season to be December, January, February. In this thesis, maintaining some degree of continuity with the more recent hemispheric studies is important because it creates the added advantage of allowing one to examine correlations between different scales of climate parameters within a similar time frame.

After a subjective inspection of annual temperature and precipitation time series from around the state, the Alaska winter season was defined to be October 1 to March 31 for the purpose of



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this study. As in the pattern climatology of Chapter 3, the thirty seasons covering the period from 1956/57 to 1985/86 form the basic data set to be analyzed.

The variety of winter weather occurring in Alaska suggests that the most appropriate way to conduct a thorough investigation of the surface climate is to divide the state into separate climate sub-regions or divisions. Moritz (1978), Overland and Heister (1980), and Wise (1988) also chose to divide the state into large geographic regions using similar climate characteristics as a basis for grouping. In the synoptic climatology presented here, the nine land-based geographic climate divisions of Alaska as designated by NOAA (1956-86) are adopted as the basis for regional study. A tenth division, the Gulf of Alaska, has been added to allow exploration of the unfrozen ocean's behavior in correspondence with the land-based divisions.

This breakdown of the state was chosen for use in this study because it was the most thorough in terms of site distribution within divisions and in terms of "quality" data longevity. The divisions were developed by NOAA based on similar geographic, temperature, and watershed characteristics. Although some of the land-based divisions are represented by more sites than others, it was decided that no single division was dangerously under-defined in terms of representing distinct physical geography and local weather phenomena. The ten climate divisions (Fig. 4.1) are listed below.

**Division 1:** Southeastern **Division 2:** South Coast

**Division 3:** Southwestern Islands **Division 4:** Copper River

**Division 5:** Cook Inlet **Division 6:** Bristol Bay

**Division 7:** West Central **Division 8:** Interior Basin

**Division 9:** Arctic Drainage **Division 10:** Gulf of Alaska

### 4.1: Data Analysis

In compiling this surface climatology, focus has been placed on the basic mean surface-level tem-

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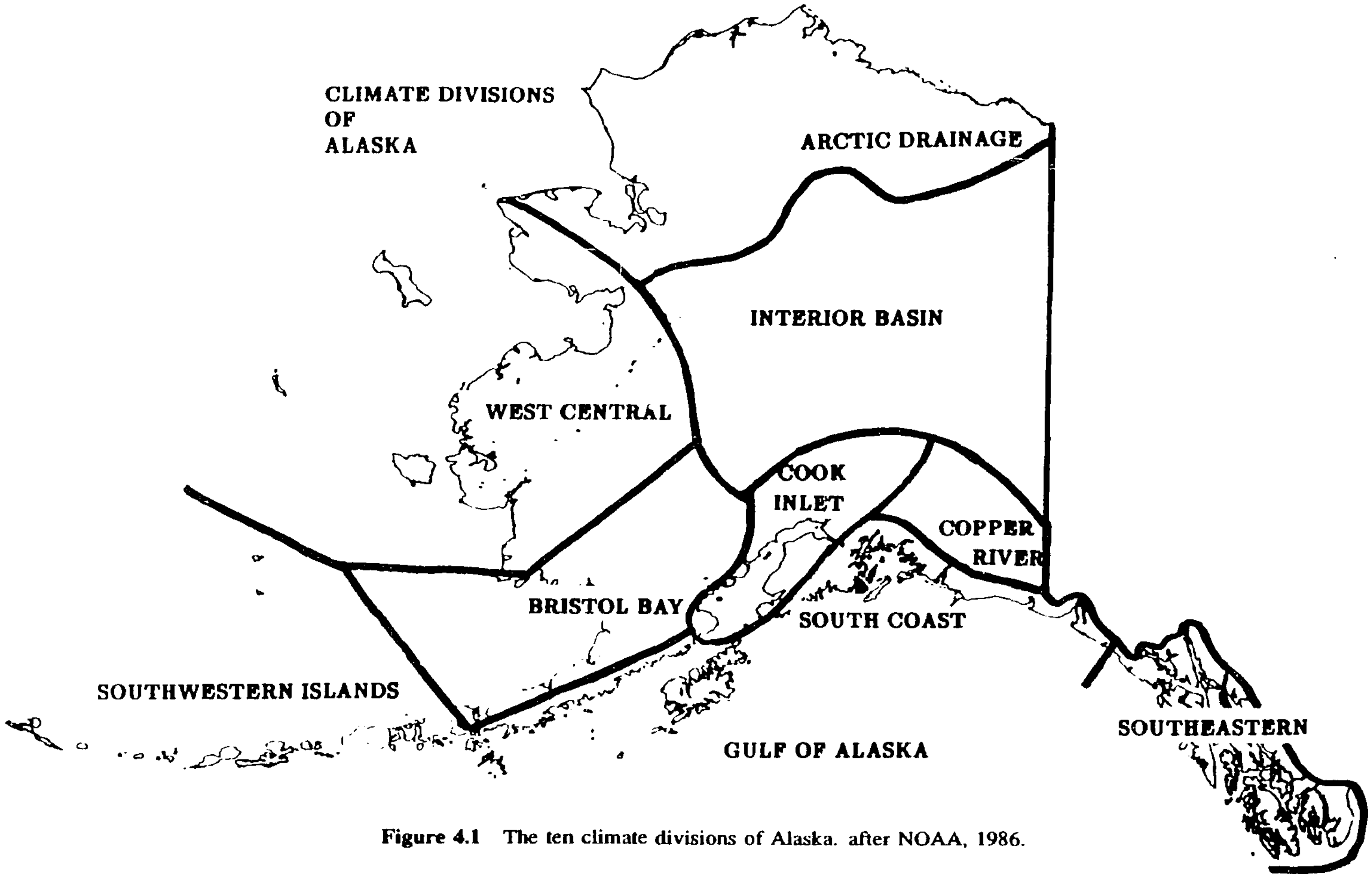


**Figure 4.1** The ten climate divisions of Alaska. after NOAA, 1986.

perature and mean surface-level precipitation characteristics of each division and the variability in these characteristics over the 30-year study period. The initial time scale of the data is that of a monthly mean. Time series of monthly mean temperature and precipitation are presented for the six winter months —October, November, December, January, February, March— covering the 30 winter seasons beginning with 1956/57 and ending with the 1985/86 winter. A 30-year mean has been calculated for each time series based on the 30 years of monthly mean values making up the time series. A *linear* least squares line has also been fit to the time series to indicate a long-term trend (thirty-year period) in climate behavior. Although the emphasis is placed on the monthly mean charcteristics of each climate division, winter season mean temperature and precipitation time series have also been calculated to show interannual winter season variability and any significant (90% C.I. level) long-term *linear* trends (Walpole and Myers, 1978) that might exist. (Note: C.I. was only calculated for *seasonal average* data approximations.)

From this analysis, we obtain six separate temperature time series corresponding to the six winter months for each of the ten geographic climate divisions. In addition, there are six different precipitation time series presented for each of the nine land-based climate divisions. No precipitation data have been used for the Gulf of Alaska region as no suitable data were available. Once the time series' had been established, each plot was examined to determine if any clear trends of warming and cooling or wet/dry periods existed in the record. From this inspection, individual anomalous periods were noted. These anomalous periods were defined in two manners. The first included single months whose mean temperature and/or precipitation values were markedly different from the 30-year mean for a specific month and division. The second included the extreme deviations embedded in persistent episodes such as notably cold months within a lower frequency cool period. In both cases, selected extreme episodes were then expanded to a higher frequency time series to determine if the anomalous behavior were due to an isolated synoptic event within the monthly mean period, or if the entire period were abnormal, hinting at an even larger-scale fluctuation. Further, anomalous

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episodes common to more than one geographic division are called to attention. These unusual periods common to more than one division may be caused by many factors including variations in atmospheric circulation and fluctuations in ocean characteristics. More detailed discussion of possible associations between atmospheric circulation, the Gulf of Alaska, and the land-based divisions are to be found in Chapter 5.

### 4.2: Results

The results of this investigation of Alaska's surface climate are presented in the following format for each of the ten geographic climate divisions: physical geography, discussion of temperature and precipitation time series, and examples of observation sites within the climate division. Note that while division climate means were used, the observation site membership of each division did fluctuate to a small extent over the thirty-year study period. All available site data were used, but only the sites that existed continuously during the entire thirty-year study period are listed in the division descriptions.

#### 4.2.1: Division 1: SOUTHEASTERN

Physical Geography: The southeast region extends from Dixon Entrance (54° $N$) along a narrow panhandle bounded by the coastal range marking the Alaska-Canada (ALCAN) border and the Gulf of Alaska north to approximately 61° $N$ near Cape Fairweather. Only the narrow western side of the Coastal range is Alaskan. The widest expanse of mainland is about thirty miles from summit to coast. There are thousands of glacier-carved islands along the coastline—remnants of the most recent glaciations. One of the largest groupings of islands forms the Alexander Archipelago. The islands act as a barrier sheltering the mainland to some extent from the impact of winter storms in the

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Gulf. The southern section of the division (i.e. near Ketchikan) is dominated by rolling terrain —the foothills of the Coastal Range. Further north, the coastal mountains marking the eastern boundary of the division become more prominent with peaks rising from near sea-level to $3100m$ or more. Large ice fields and glaciers (Post and LaChapelle, 1971) left over from the last ice advance remain active in the higher elevations. Tidewater glaciers are still present along the fjord-cut coast. From the central section to the northern reaches of the division, the Coastal Range continues to increase in elevation with peaks which exceed $4500m$. The glacier/stream-cut coastlines also become more intricate. This is the region of the tidewater glaciers found in Glacier Bay and the "fjord canals" leading inland to the huge snowfields of the St. Elias Mountains and Canada.

Climate: The climate of the division is basically maritime. Because of its geographic location, its precipitation amounts and temperature values are influenced by the ocean's climate.

Precipitation is in the form of rain and heavy snow, even at sea-level, and temperatures are again slightly cooler than the areas to the south. The large coastal mountain barrier along the eastern border of the division and the onshore flow of moisture-laden Pacific air combine to produce large precipitation totals (Fig. 4.2, Fig. 4.3, and Table 4.1a,b) throughout the entire division. October is usually the wettest month in terms of a long-term monthly average. The long-term mean value for October is $365mm$. March is the driest period with an average of $158mm$. All six months exhibit a large interannual variability. November and December precipitation seems to have decreased over the thirty years. October and January values have increased. The early 1960's are wetter than the thirty-year mean in all months. This wet period is followed by a dry period from 1965-1974. This also corresponds to the cool episode in the temperature record. Following the dry decade, precipitation is again more variable. Extreme anomalies include October 74 (+), October 78 (+), October 75 (-), December 83(-), January 85 (+), January 76 (+), November 69 (+), and February

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62 (-). long-term season.(Fig.4.3). There is no significant long-term trend in the seasonal average precipitation data for the division.

Average monthly mean temperatures (Figs. 4.4 and 4.5, Table 4.1a,b) range from $6.6°C$ in October to $-1.8°C$ in January. The largest decrease in monthly mean temperatures occurs from October to November when the change in temperature is $-4.7°C$. Throughout the thirty years of investigation, December, January, and February were the most variable. The most prolonged period of below normal temperatures occurred in January from 1964-1975. This cold episode was preceded by a five-year period of above normal January temperature. Major short-term anomalies included January 1981 (warm) and February 1981 (cold). There is no significant long-term trend in the seasonal average temperature data for the division.

NOAA Observation Sites: Among the major observation sites in this division are: Sitka, Juneau, Ketchikan, Little Port Walter, Wrangell, Annette, and Annex Creek.

### 4.2.2: Division 2: SOUTH COAST

Physical Geography: The South Coast division forms an arc along the north coast of the Gulf of Alaska. It extends from the Fairweather range west to Port Moller on the Alaska Peninsula. Kodiak Island is also included in the division because of its exposure to storm activity in the Gulf of Alaska and the Shelikof Strait. The Cook Inlet region is considered to be a separate division because it is sheltered from the Gulf by the mountains along the eastern Kenai Peninsula. The area from Cape Fairweather to the Kenai Peninsula is dominated by the snow/ice-covered Chugach mountains. Huge tidewater glaciers and alpine icefields (Post and LaChapelle, 1971) remain active along the coastal side of these mountains. Prince William Sound alone contains nearly 100 tidewater glaciers. The gulf coastline is characterized by intricate fjords and bays (i.e. Prince William Sound, Resurrection Bay, Icy Bay, and Yakutat Bay) resulting from the glaciation.

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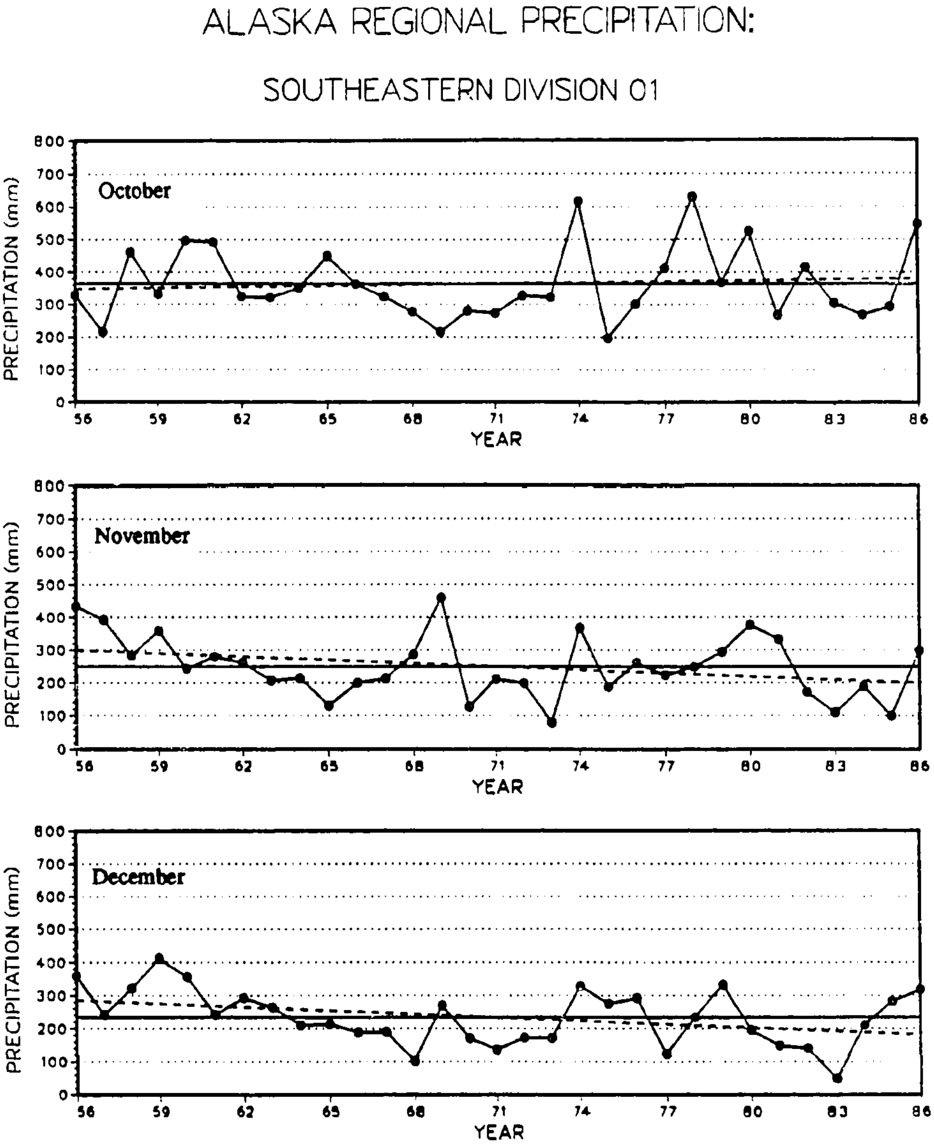


**Figure 4.2** Southeastern Division 1 monthly mean precipitation- 1956 to 1986 (winter months). year (x-axis) is the actual date of the data, not the winter season date; solid line with points indicated: data, solid line: thirty-year mean data value for month's data depicted, dashed line: trend (linear least squares fit to data); units are *mm*.

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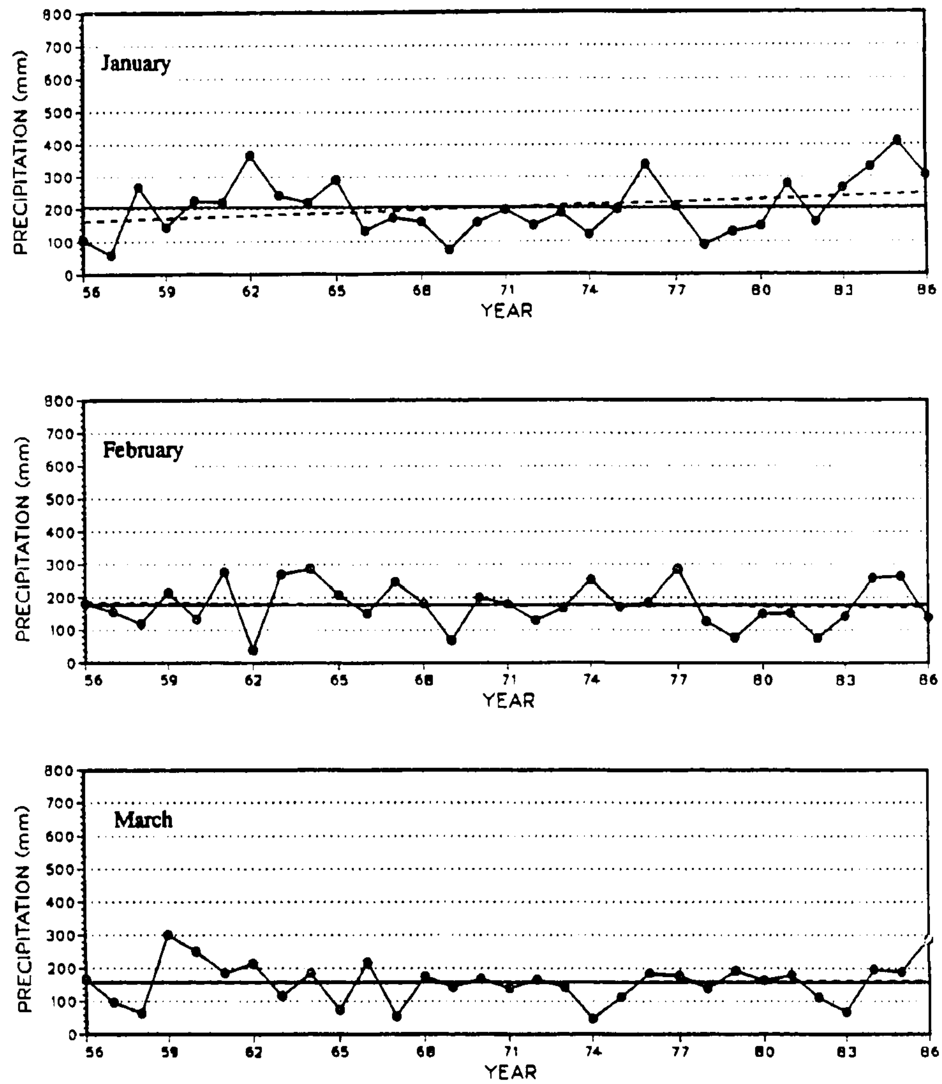


**Figure 4.2cont'd** Southeastern Division 1 monthly mean precipitation-1956 to 1986 (winter months). units are *mm*.

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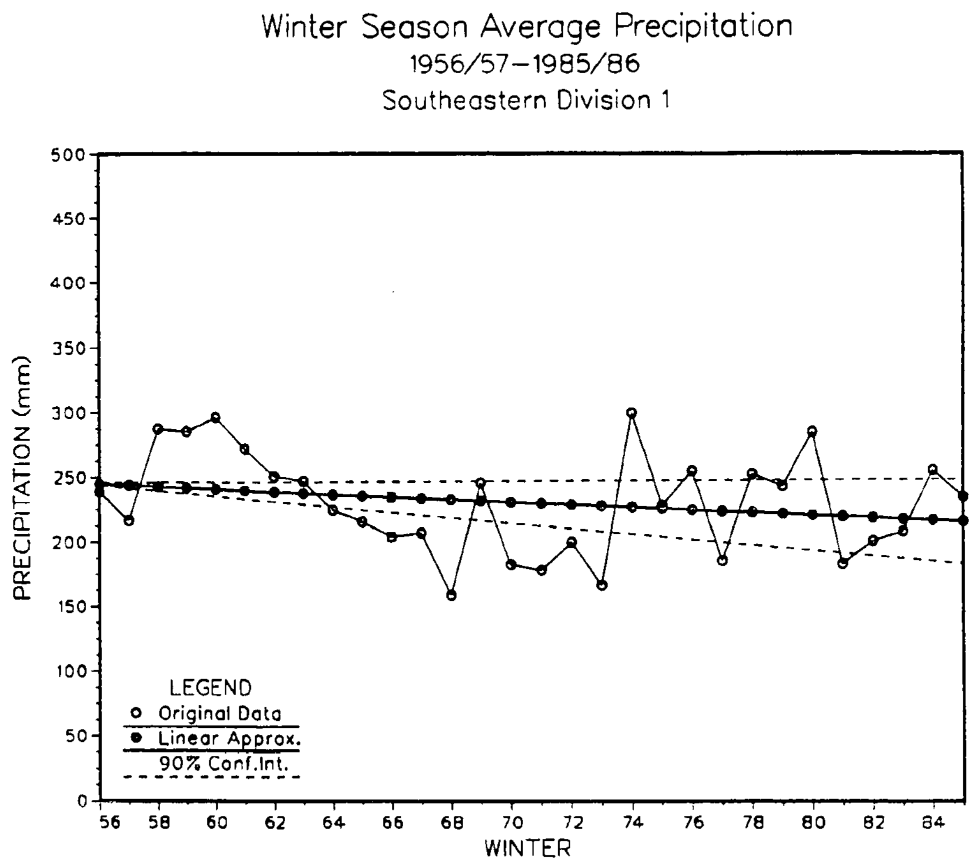


**Figure 4.3** Southeastern Division 1 Winter Season average precipitation- Winter 1956/57 to 1985/86. winter season data is an average of the six winter months' (October, November, December, January, February, and March) monthly mean data; units are *mm*.

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**Table 4.1a,b** Southeastern Division 1 monthly mean temperature and precipitation. Winter Season extremes (1956/57 to 1985/86) (a) monthly mean temperature, (b) monthly mean precipitation.

**a** Monthly Mean Temperature Statistics: Southeastern Division Winter Season 1956-1986

| Month | Max. T | Min. T | Mean T |
|---|---|---|---|
| Oct. | 8.2°$C$ | 4.5°$C$ | 6.6°$C$ |
| Nov. | 4.9 | -4.0 | 1.9 |
| Dec. | 3.2 | -6.1 | -0.5 |
| Jan. | 4.2 | -9.3 | -1.8 |
| Feb. | 4.9 | -7.0 | 0.1 |
| Mar. | 4.8 | -0.9 | 1.9 |

**b** Monthly Mean Precipitation Statistics: Southeastern Division Winter Season 1956-1986

| Month | Max. P | Min. P | Mean P |
|---|---|---|---|
| Oct. | 630$mm$ | 197 | 365 |
| Nov. | 460 | 80 | 249 |
| Dec. | 411 | 49 | 233 |
| Jan. | 410 | 59 | 206 |
| Feb. | 288 | 38 | 177 |
| Mar. | 301 | 47 | 158 |

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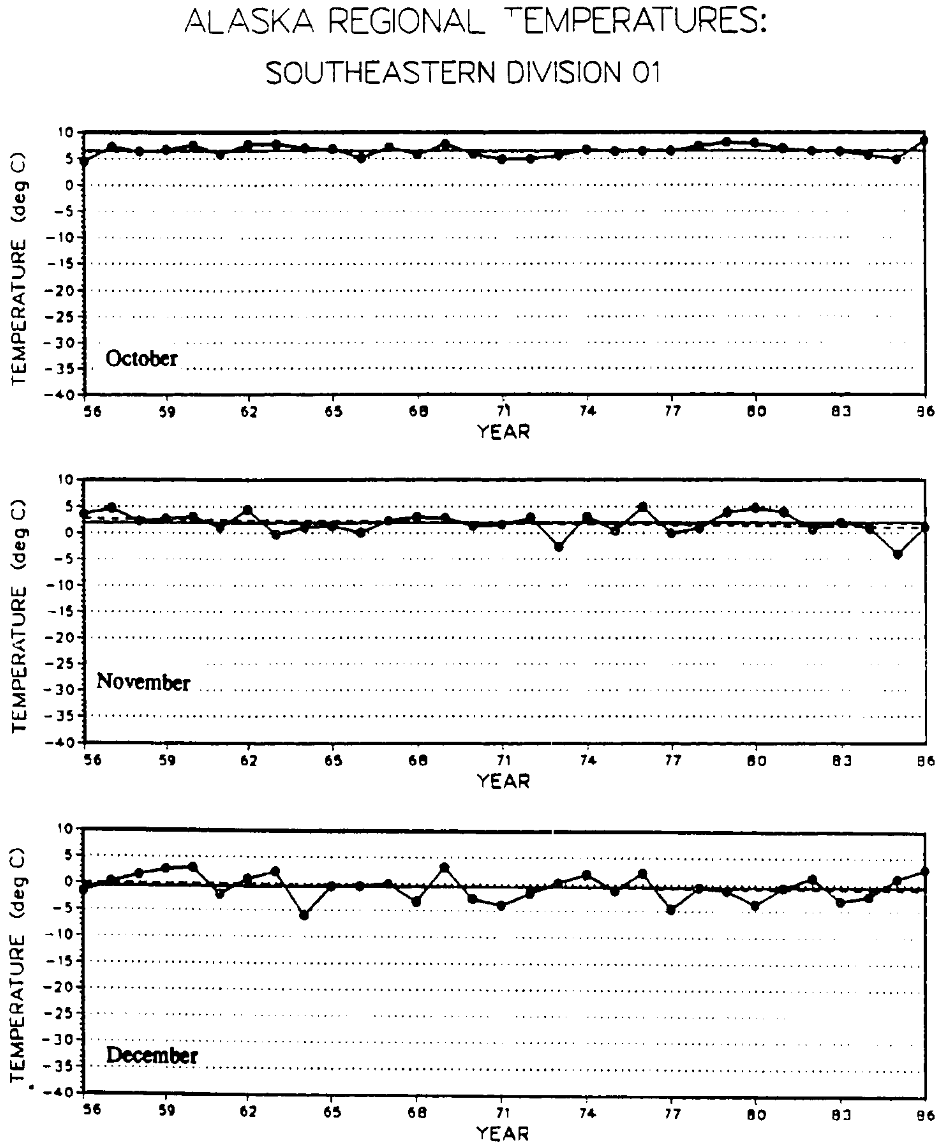


**Figure 4.4** Southeastern Division 1 monthly mean temperatures-1956 to 1986 (winter months). year (x-axis) is the actual date of the data, not the winter season date; solid line with points indicated: data, solid line: thirty-year mean data value for month's data depicted, dashed line: trend (linear least squares fit to data); units are °*C*.

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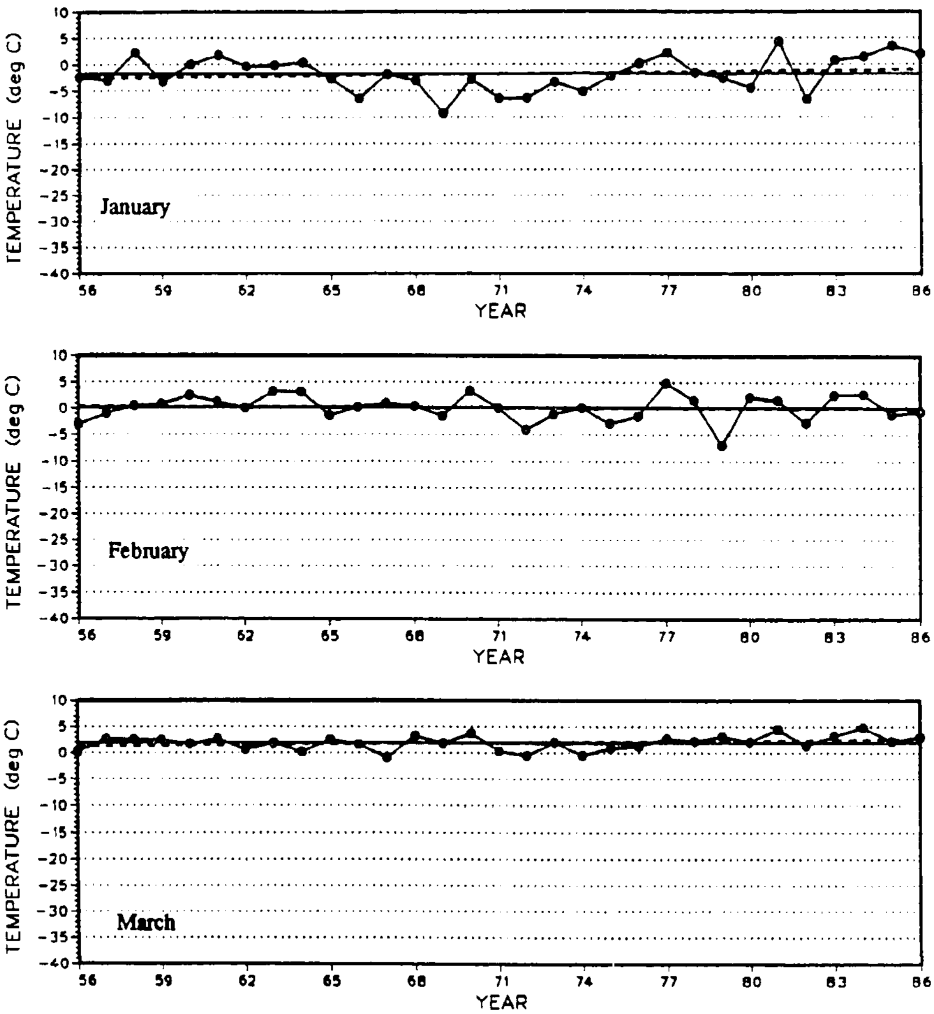


**Figure 4.4cont'd** Southeastern Division 1 monthly mean temperatures-1956 to 1986 (winter months). units are $^\circ C$.

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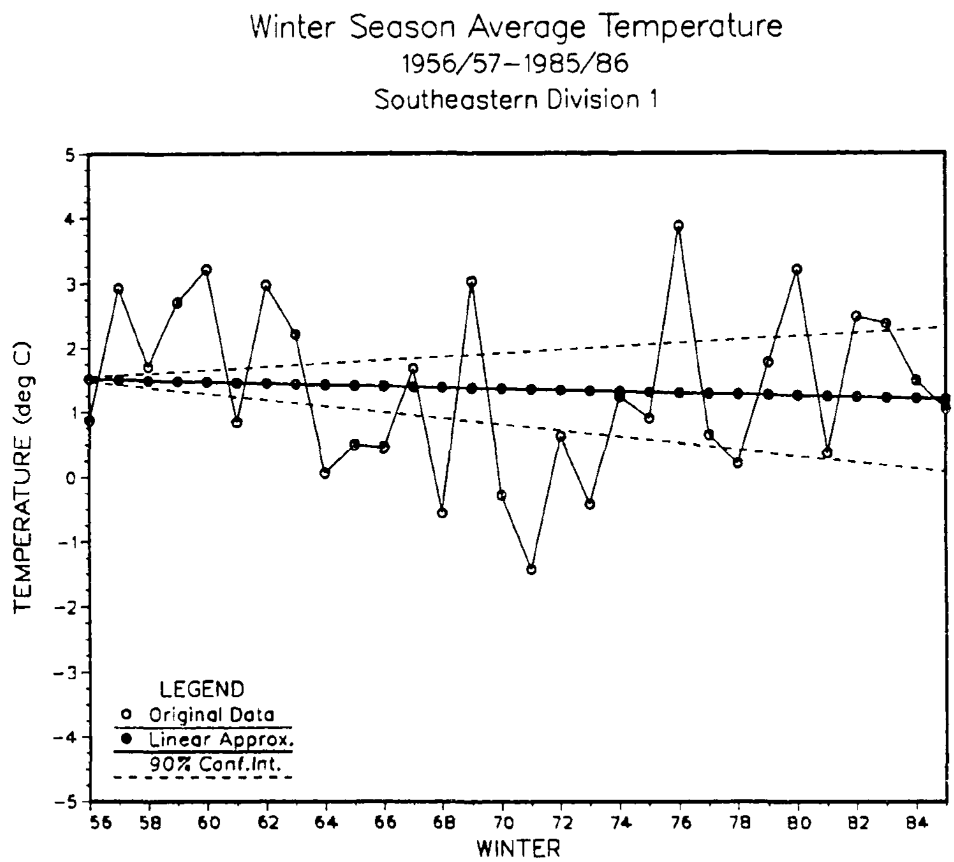


**Figure 4.5** Southeastern Division 1 Winter Season average temperatures- Winter 1956/57 to 1985/86. winter season data is an average of the six winter months' (October, November, December, January, February, and March) monthly mean data; units are °$C$.

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Climate: The division's climate is especially maritime. There is no protective mountain barrier sheltering the division from winter Gulf storms. Precipitation in the division is primarily orographic in nature as the division is bounded on the north by the Chugach mountains. The orographic influence of the mountains, a constant supply of moisture from the pre-dominantly ice-free gulf and mild temperatures combine to give the division some of the highest precipitation totals (Figure 4.6, Figure 4.7, Table 4.2a,b) in the state. Precipitation falls as snow or rain at sea level and heavy snow at higher elevations. Thompson Pass holds the state single season snowfall record at over $1500mm$. Drizzle and fog are not unusual in the division's western sector and the sheltered areas of the eastern sector.

October is the wettest month ($280mm$ ave.) in this division, but the wettest single month was November 1976 when $718mm$ were recorded. This period also corresponds to the period of warmest sea surface temperatures in the Gulf of Alaska. March is the driest period. Although all six months show a large amount of interannual variability in precipitation amounts, the highest amplitude fluctuations occur in November, December, and January. Long-term trends in monthly mean values suggest an increase in precipitation in December and January. October precipitation has also increased. November amounts have decreased. There is comparatively little change in the February or March records. As with the Southeast division, the period between 1965 and 1974 is dryer than average. This is especially notable in the January record. Prior to the dry period, precipitation was close to average. After the dry period, the record exhibits a large amount of interannual variability in all months. Variations of $200mm$ or more are not uncommon from season to season (same month) in this unsettled period. The most pronounced anomalies include November 76 (+), December 69 (+), December 84(+), December 85 (+), January 77 (+), January 81 (+), January 85(+), February 77 (+), February 78 (-), and October 85 (-). There is no significant long-term trend in the seasonal average precipitation data for the division.

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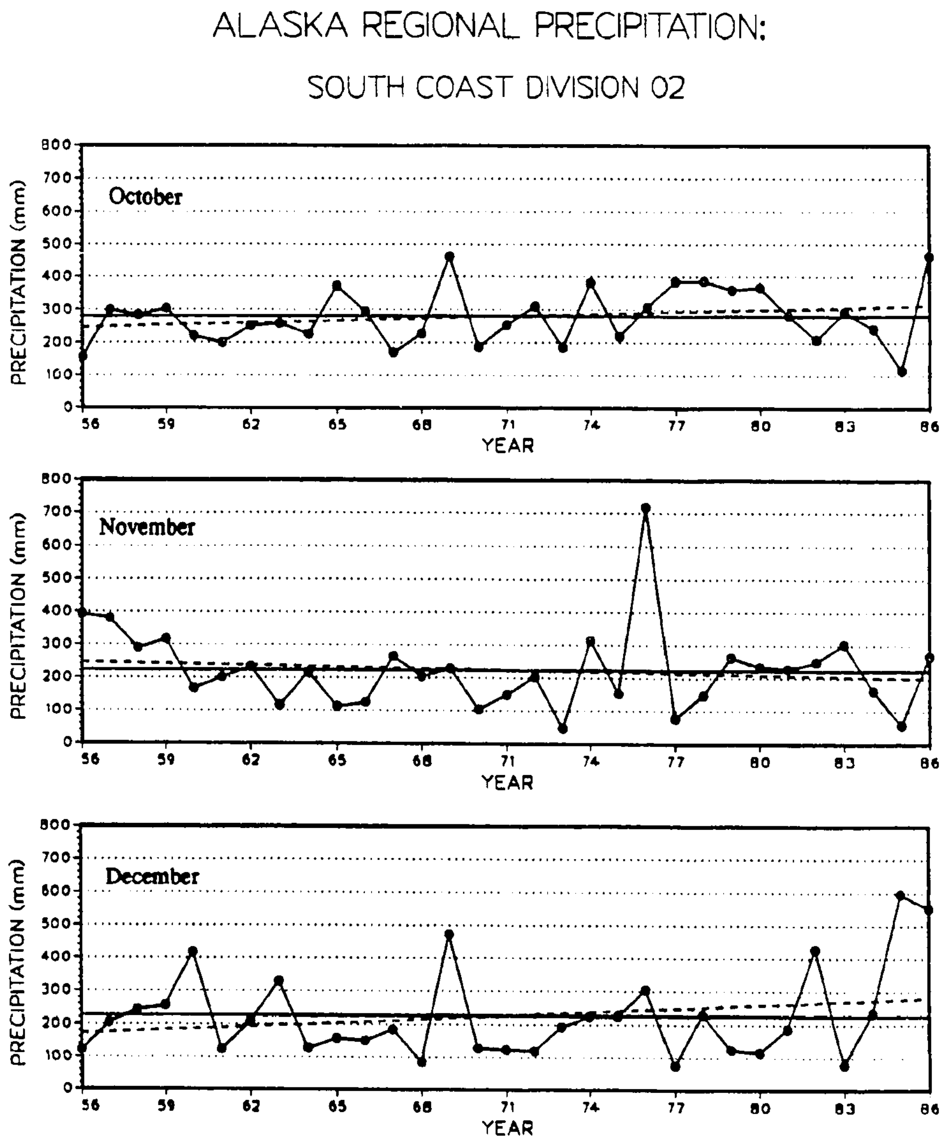


**Figure 4.6** South Coast Division 2 monthly mean precipitation- 1956 to 1986 (winter months). year (x-axis) is the actual date of the data, not the winter season date; solid line with points indicated: data, solid line: thirty-year mean data value for month's data depicted, dashed line: trend (linear least squares fit to data); units are *mm*.

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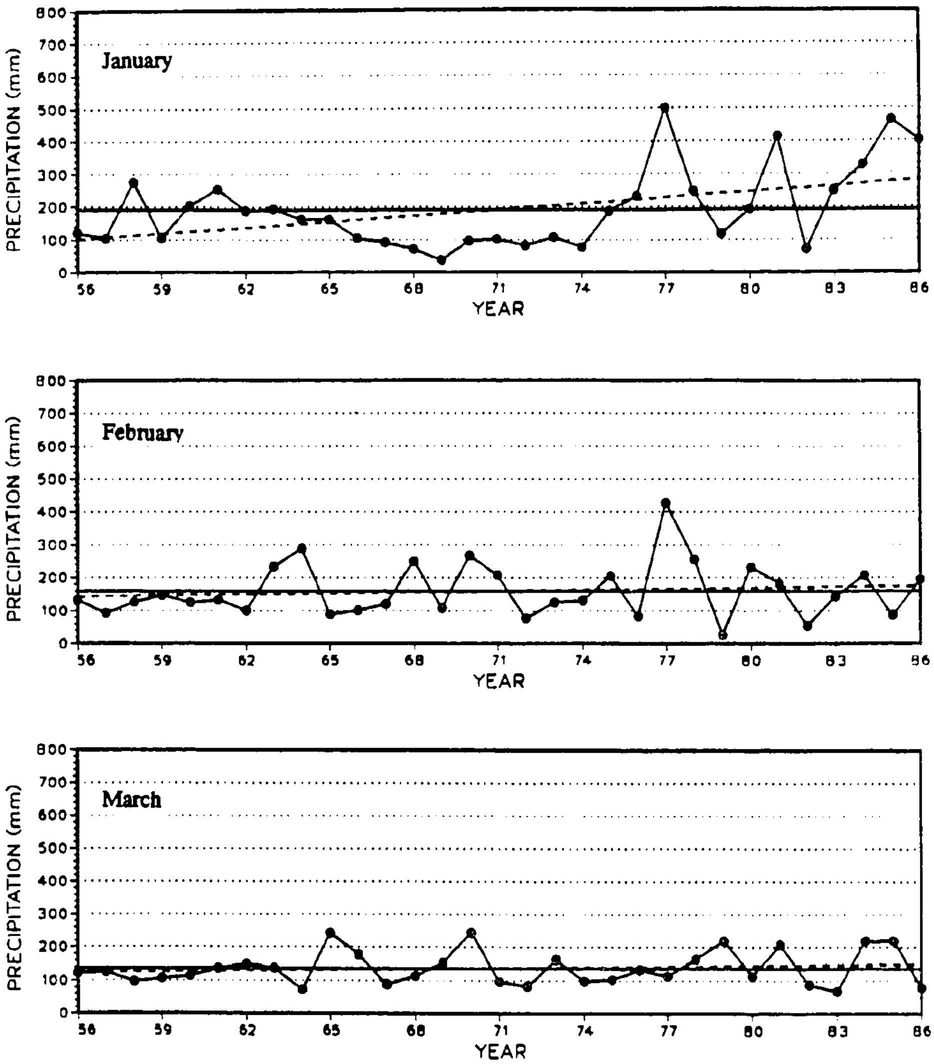


**Figure 4.6cont'd** South Coast Division 2 monthly mean precipitation-1956 to 1986 (winter months). units are *mm*.

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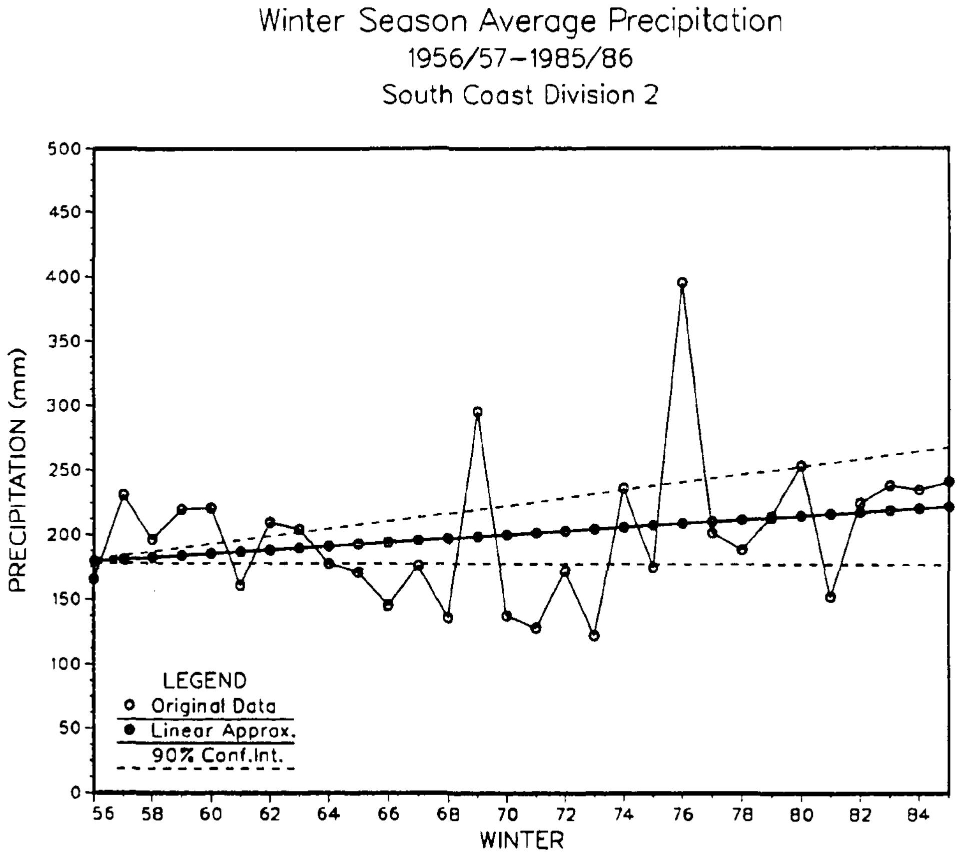


**Figure 4.7** South Coast Division 2 Winter Season average precipitation- Winter 1956/57 to 1985/86. winter season data is an average of the six winter months' (October, November, December, January, February, and March) monthly mean data; units are *mm*.

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**Table 4.2a,b** South Coast Division 2 monthly mean temperature and precipitation. Winter Season extremes (1956/57 to 1985/86) (a) monthly mean temperature, (b) monthly mean precipitation.

**a** Monthly Mean Temperature Statistics: South Coast Division Winter Season 1956-1986

| Month | Max. T | Min. T | Mean T |
|---|---|---|---|
| Oct. | 6.7°$C$ | 1.0°$C$ | 4.1°$C$ |
| Nov. | 3.8 | -5.6 | -0.3 |
| Dec. | 2.2 | -11.1 | -3.1 |
| Jan. | 2.2 | -8.9 | -3.6 |
| Feb. | 2.1 | -8.6 | -2.5 |
| Mar. | 2.6 | -5.8 | -0.8 |

**b** Monthly Mean Precipitation Statistics: South Coast Division Winter Season 1956-1986

| Month | Max. P | Min. P | Mean P |
|---|---|---|---|
| Oct. | 462$mm$ | 117 | 280 |
| Nov. | 718 | 47 | 224 |
| Dec. | 595 | 76 | 226 |
| Jan. | 499 | 37 | 191 |
| Feb. | 427 | 26 | 160 |
| Mar. | 244 | 68 | 137 |

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As with the Southeastern division, this division, too, experiences maximum temperature variability (Figs. 4.8 and 4.9, Table 4.2a) in December, January, and February. The coldest month is January with a mean temperature of $-3.6°C$. The warmest month is October with a mean temperature of $4.1°C$. October is also the only winter month with a mean monthly temperature above the freezing mark. The most prolonged period of below normal temperatures is similar to that seen in the Southeast division record— January of the period 1966 to 1976. Both January and February show an extended period of above average temperatures from 1957-1964, just prior to the cold episode. Individual anomalous months within the record include December 1968 (-), December 1969 (+), January 1981 (+), and February 1979 (-). There is no significant long-term trend in the seasonal average temperature data for the division.

NOAA Observation Sites: Major observation sites within this division are: Cordova, Seward, Yakutat, and Kitoi Bay.

### 4.2.3: Division 3: SOUTHWESTERN ISLANDS

Physical Geography: The Southwestern division is primarily composed of the Aleutian Island chain. However, because of their similar climates and geographic setting, the Pribilof Islands are also part of the division. The major difference between the Pribilof Islands and the Aleutian Islands is that the Pribilof Islands are more likely to be surrounded by ice-covered water. The division covers the area between $58°N$ to $45°N$ and $160°W$ to $170°E$. The topography of the islands reflects their volcanic origin as part of the Pacific Ring of Fire. The islands are a mixture of low-lying exposed areas, jagged coastlines, and volcanic peaks of $1500m$ or more.

Climate: The climate in the division is dominated by the effects of the sharp baroclinic zone created by the "meeting" of the warm Northeast Pacific Ocean flowing through the islands from the south and the cold, sometimes ice-covered southern Bering Sea to the north. This area is one

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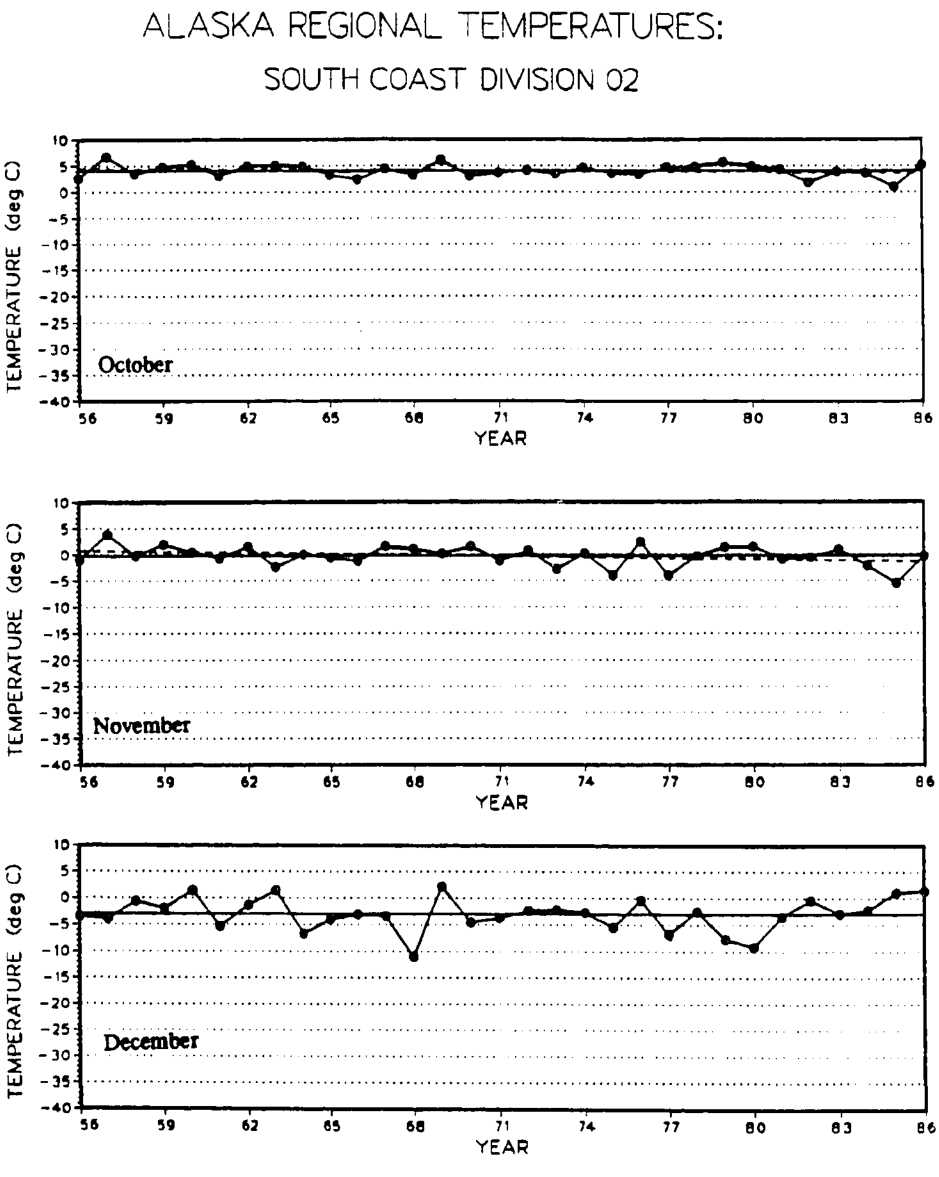


**Figure 4.8** South Coast Division 2 monthly mean temperatures-1956 to 1986 (winter months). year (x-axis) is the actual date of the data, not the winter season date; solid line with points indicated: data, solid line: thirty-year mean data value for month's data depicted, dashed line: trend (linear least squares fit to data); units are $^\circ C$.

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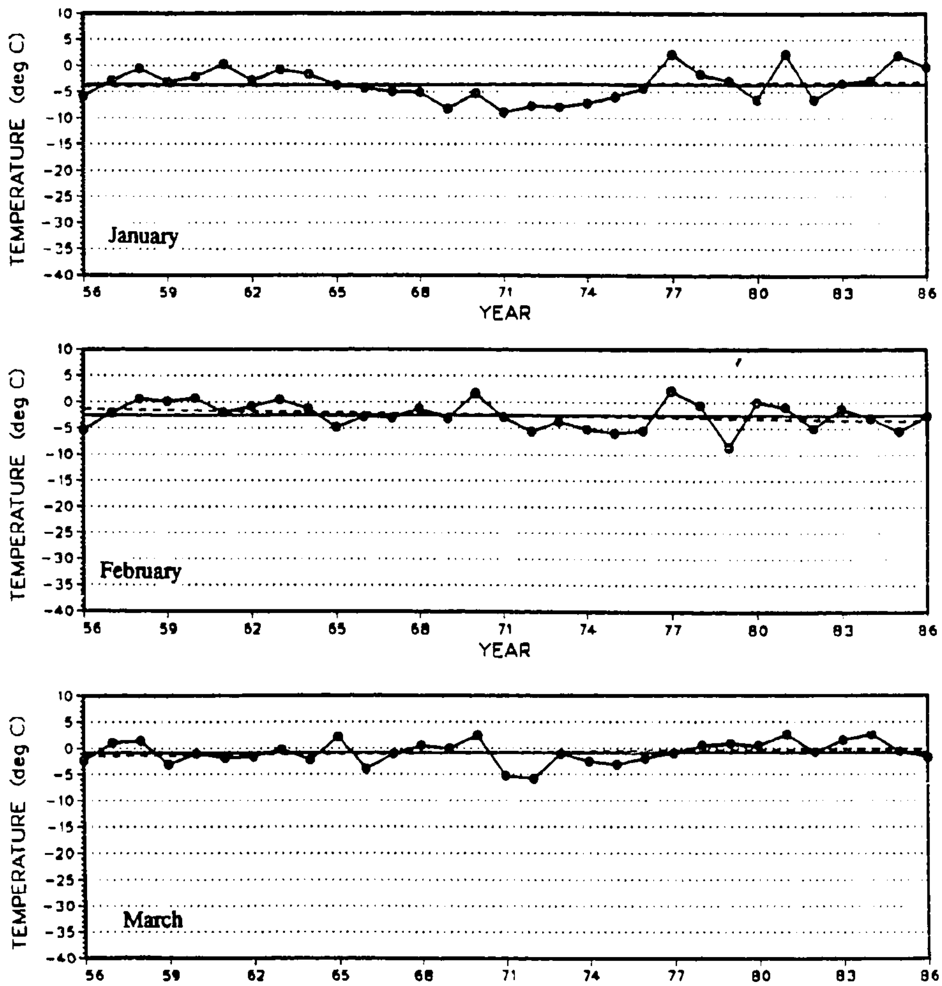


**Figure 4.8** South Coast Division 2 monthly mean temperatures-1956 to 1986 (winter months). units are °$C$.

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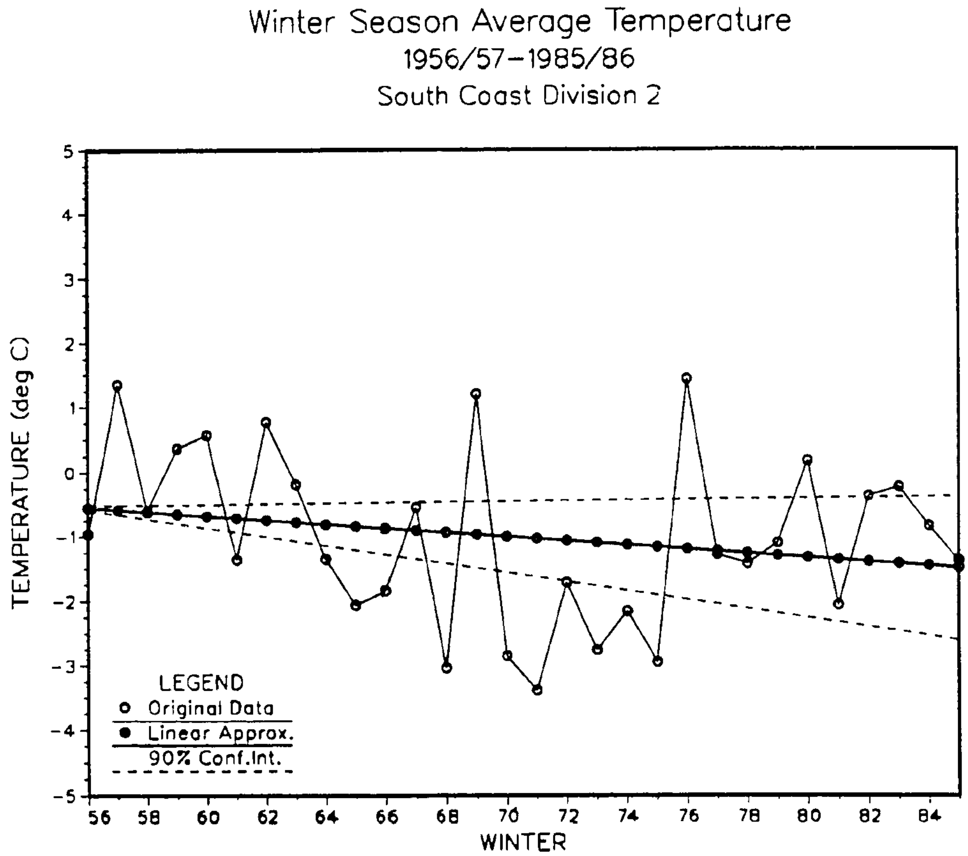


**Figure 4.9** South Coast Division 2 Winter Season average temperatures- Winter 1956/57 to 1985/86. winter season data is an average of the six winter months' (October, November, December, January, February, and March) monthly mean data; units are $^\circ C$.

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of the world's most extensively documented regions of intense cyclogenesis (Gyakum *et al.*, 1988; Anderson *et al.*, 1988). The winter Aleutian Low which persists in the vicinity of this discontinuous temperature zone is perhaps the most dynamic atmospheric feature in the division. The baroclinic zone also serves as a birthplace and an area of intensification for many of the Pacific winter storms that reach the West Coast of the lower 48 United States and Canada. Further, it is also an area of cyclolysis for storms that lose intensity traveling across the central Pacific (Gyakum *et al.*,1989). Because of the frequency of intense storms in the division, strong winds are the most predominant meteorological element. Precipitation falls in the form of rain, sleet, snow, and drizzle throughout most of the winter season. The maritime characteristics of the division also make the islands susceptible to dense ocean-based fog.

Precipitation values (Figs. 4.10 and 4.11, Table 4.3b) range from $113mm$ in October and November to $67mm$ in February. The extreme interannual variability of the South Coast and Southeastern divisions is not apparent in this division's observations. Over the thirty year period, November and December show an indication of an increase in precipitation amounts. The other four months remain relatively unchanged. The only unusual periods in the record are December 69 (+), February 63 (-), February 65 (+), March 65 (+), and December 83 (+). There is a significant increasing long-term trend in the seasonal average precipitation data for the division.

Temperatures are similar to those of the other Pacific coast divisions, rather than those of the more northern Bering coast divisions. However, the strong winds frequently create windchill temperatures similar to those of the northern divisions.

Monthly mean temperatures (Figs. 4.12 and 4.13, Table 4.3a) range from $4.8°C$ in October to $-1.8°C$ in February. The most variable months are January, February, and March. March 78-84 is the only extended period of above normal temperatures. There is no significant long-term trend in the seasonal average temperature data for the division.

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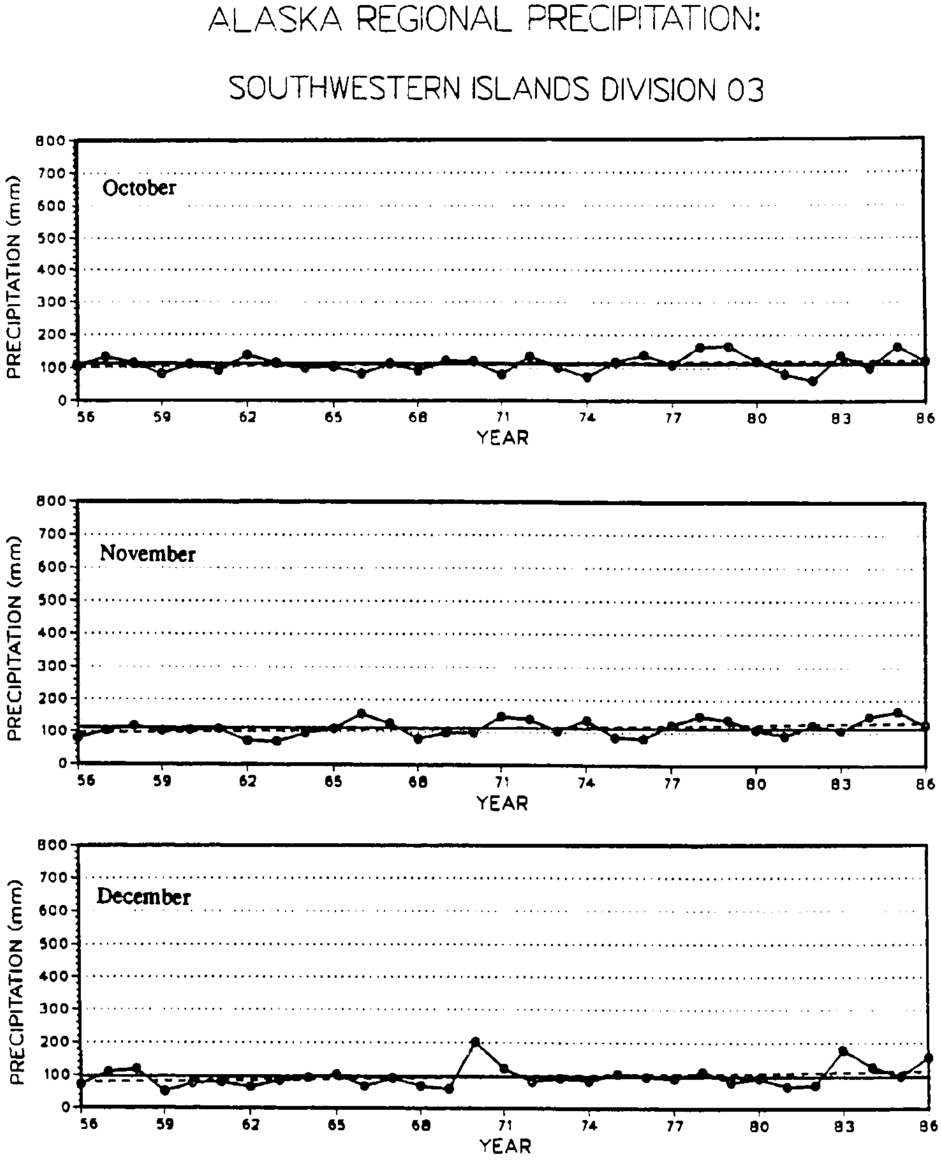


**Figure 4.10** Southwestern Islands Division 3 monthly mean precipitation- 1956 to 1986 (winter months). year (x-axis) is the actual date of the data, not the winter season date; solid line with points indicated: data, solid line: thirty-year mean data value for month's data depicted, dashed line: trend (linear least squares fit to data); units are *mm*.

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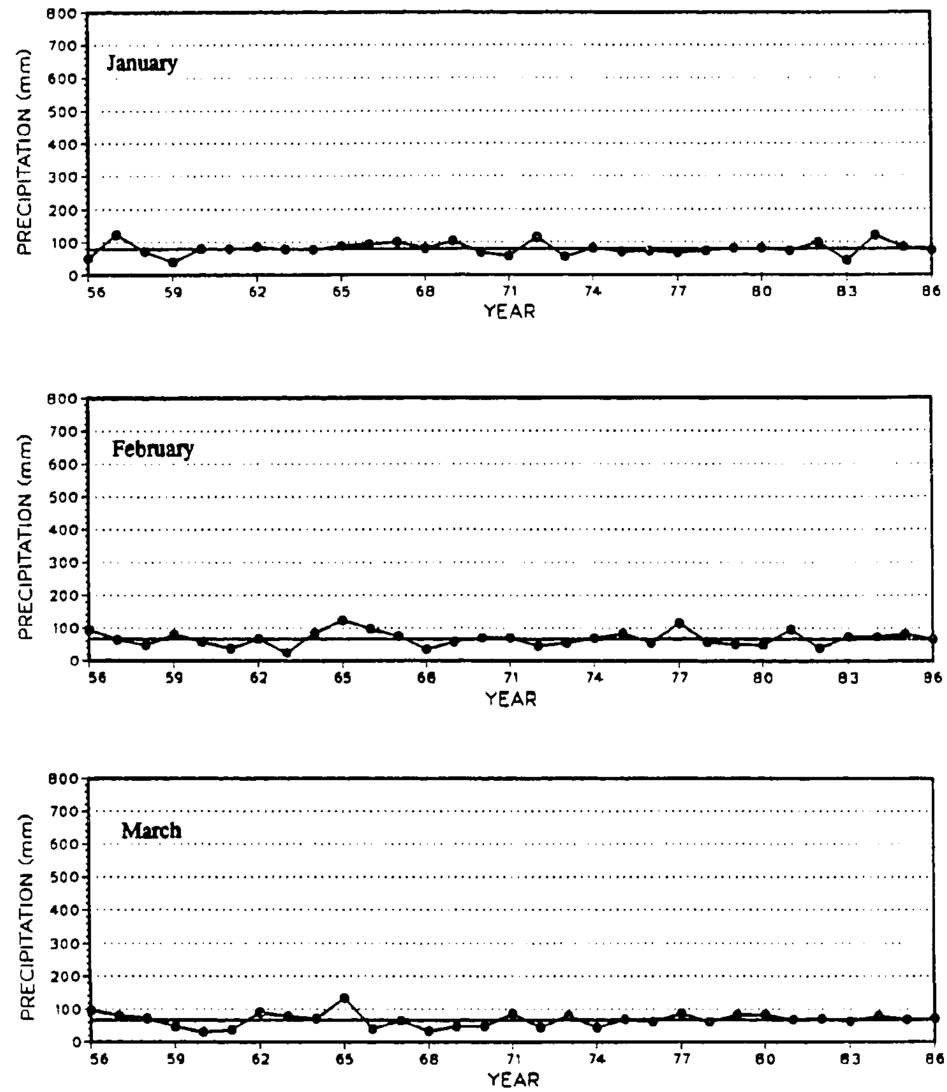


**Figure 4.10cont'd** Southwestern Islands Division 3 monthly mean precipitation-1956 to 1986 (winter months). units are *mm*.

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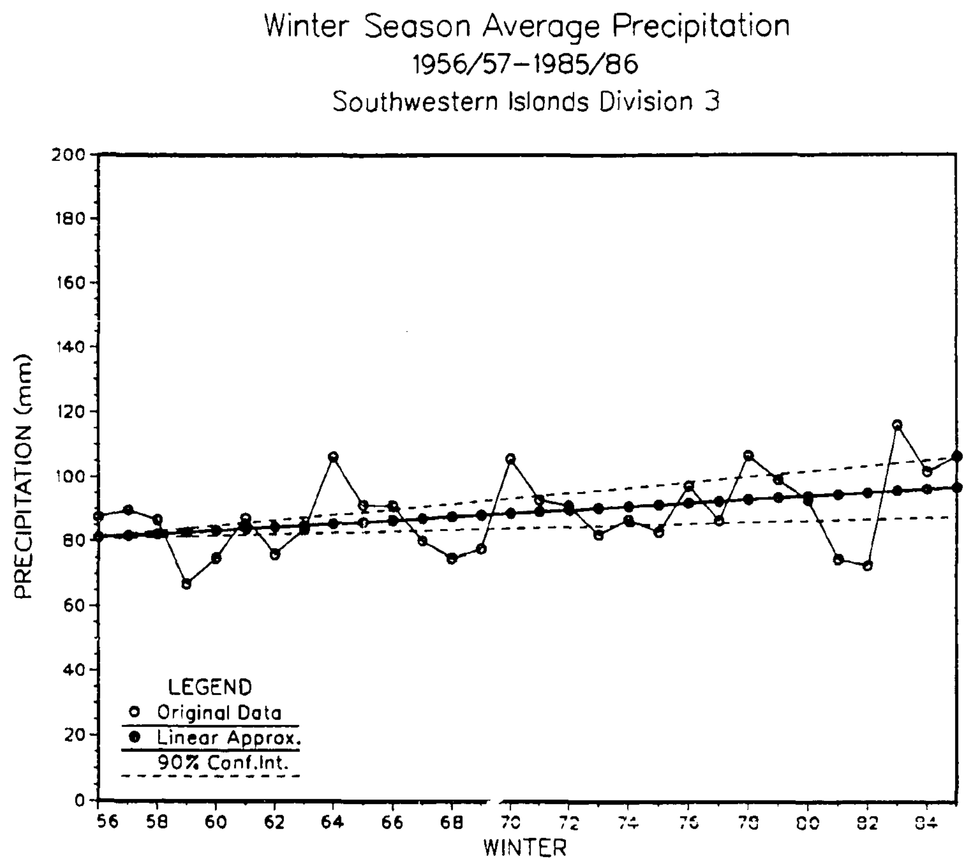


**Figure 4.11** Southwestern Islands Division 3 Winter Season average precipitation- Winter 1956/57 to 1985/86. winter season data is an average of the six winter months' (October, November, December, January, February, and March) monthly mean data; units are *mm*.

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**Table 4.3a,b** Southwestern Islands Division 3 monthly mean temperature and precipitation. Winter Season extremes (1956/57 to 1985/86) (a) monthly mean temperature, (b) monthly mean precipitation.

**a**

Monthly Mean Temperature Statistics:
Southwestern Islands Division
Winter Season 1956-1986

| Month | Max. T | Min. T | Mean T |
|---|---|---|---|
| Oct. | 5.9°$C$ | 3.6°$C$ | 4.8°$C$ |
| Nov. | 3.6 | 0.0 | 1.9 |
| Dec. | 2.3 | -2.9 | -0.3 |
| Jan. | 1.4 | -3.6 | -1.0 |
| Feb. | 0.5 | -5.0 | -1.8 |
| Mar. | 1.4 | -3.9 | -1.0 |

**b**

Monthly Mean Precipitation Statistics:
Southwestern Islands Division
Winter Season 1956-1986

| Month | Max. P | Min. P | Mean P |
|---|---|---|---|
| Oct. | 164$mm$ | 62 | 113 |
| Nov. | 166 | 70 | 113 |
| Dec. | 202 | 51 | 97 |
| Jan. | 123 | 39 | 79 |
| Feb. | 124 | 24 | 67 |
| Mar. | 134 | 30 | 68 |

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# ALASKA REGIONAL TEMPERATURES:

## SOUTHWESTERN ISLANDS DIVISION 03

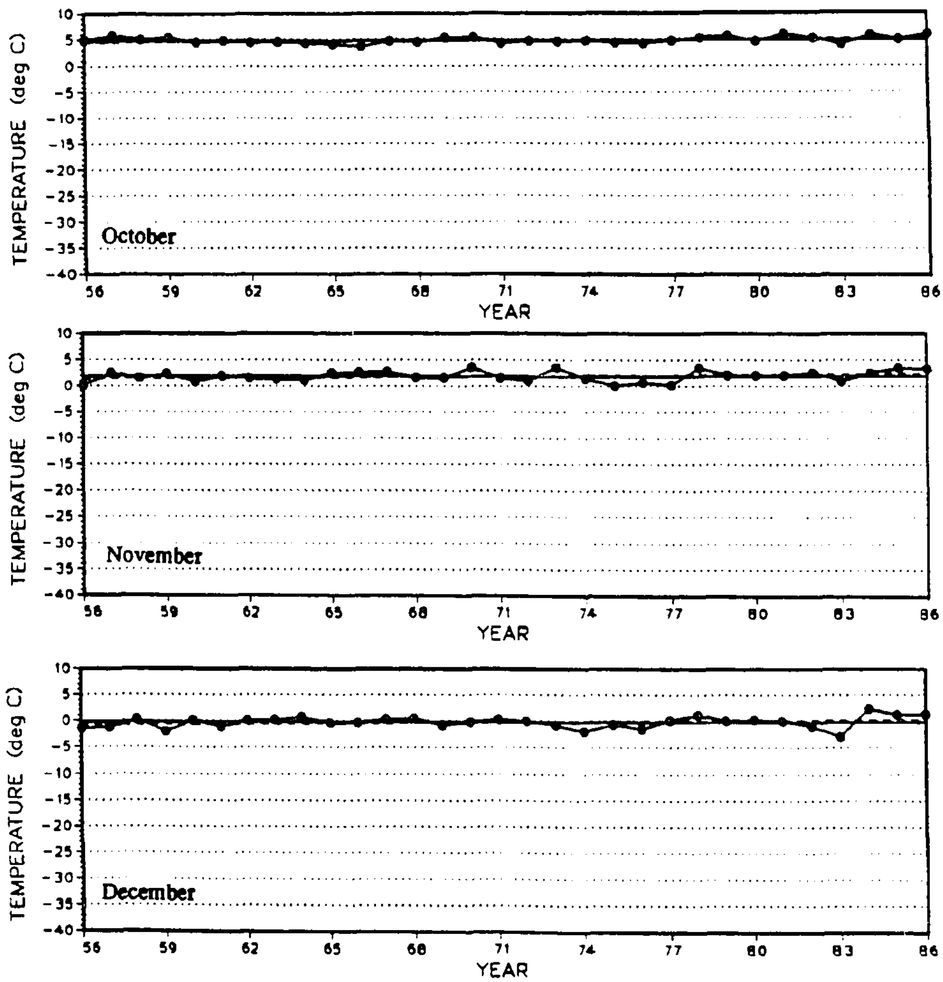


**Figure 4.12** Southwestern Islands Division 3 monthly mean temperature- 1956 to 1986 (winter months). year (x-axis) is the actual date of the data, not the winter season date; solid line with points indicated: data, solid line: thirty-year mean data value for month's data depicted, dashed line: trend (linear least squares fit to data); units are °$C$.

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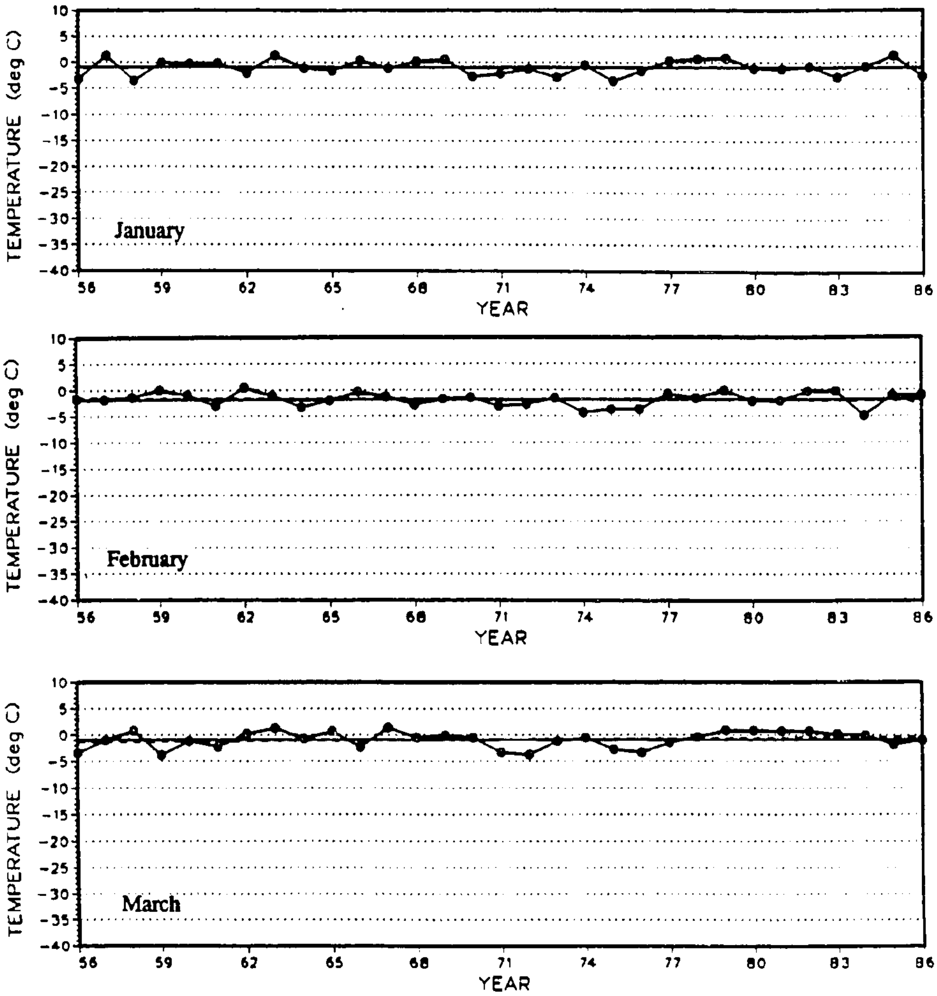


**Figure 4.12cont'd** Southwestern Islands Division 3 monthly mean temperature-1956 to 1986 (winter months). units are °$C$.

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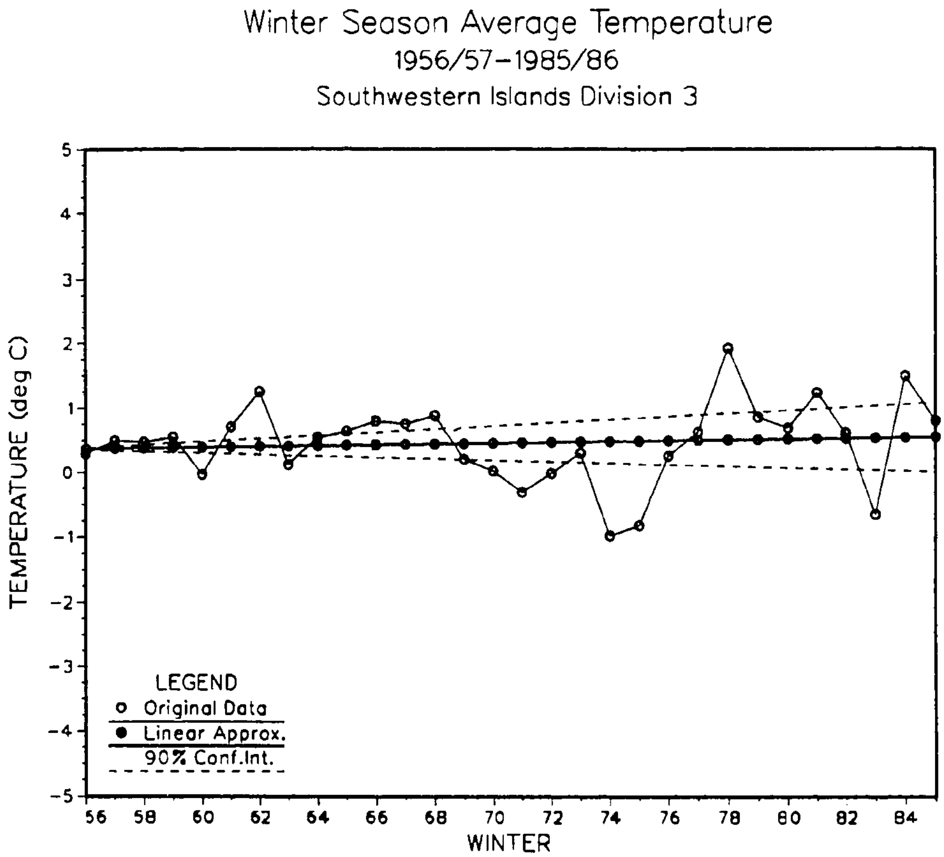


**Figure 4.13** Southwestern Islands Division 3 Winter Season average temperature– Winter 1956/57 to 1985/86. winter season data is an average of the six winter months' (October, November, December, January, February, and March) monthly mean data; units are $^{\circ}C$.

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NOAA Observation Sites: Major observation sites within this region are: Adak, Attu, Cold Bay, and St. Paul Island.

### 4.2.4: Division 4: COPPER RIVER

Physical Geography: Although the Copper River division is small, its average elevation is the greatest of all the climate divisions in Alaska. The division is located along the ALCAN border between the interior region and the huge icefields of the South Coast division. Its northwest corner meets the Cook Inlet division along the eastern Talkeetna mountains. Both the snow/glacier-covered Wrangell Mountains and the St. Elias range are located in this division. With the exception of the northwest corner of the division, elevations range from $3000m$ to over $4500m$ . These snowfields provide the headwaters of the Copper River. The mountains also act as a secondary barrier for maritime air flowing northward from the gulf.

Climate: This division is characterized by a transitional climate. It has elements of maritime and continental zones. Although the actual water precipitation totals are less than those of the coastal divisions, the mountains in this division receive a considerable amount of snow. In fact, most of its winter season precipitation is in the form of snow.

Precipitation values (Figs. 4.14 and 4.15, Table 4.4b) range from $42mm$ in October to $24mm$ in March. It is important to note that these observations are from the lower elevations within the division. The higher elevations tend to receive much larger amounts of orographically- enhanced precipitation as the mountains trap the inland flow of moisture from the south. The long-term trend fit to the monthly-mean time series suggests that precipitation totals in all six months have decreased. This trend is further supported by the fact that November 76 and October 72 are the only months

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after the 1968 season to have above normal precipitation totals. There is a significant decreasing long-term trend in the seasonal average precipitation data for the division.

Winter temperatures (Figs. 4.16 and 4.17, Table 4.4a) are slightly cooler than those of the truly coastal divisions to the south but not as extreme as those of the interior division to the north. Thirty-year mean monthly values range from $-3.1°C$ in October to $-19.5°C$ in February. The slightly continental nature of this division's climate is also reflected in the larger intra- and interannual variability of temperatures. The highest amplitude fluctuations occur in December, January, and February. The long-term records suggest a decrease in temperatures for February and November. The other four months show no evidence of a long-term trend. However, as seen in the coastal division, the period between 1965 and 1977 is colder than normal in January. December and February are also colder than normal for all but one or two seasons during this period. The cold period is once again preceded by several seasons of above normal temperatures and followed by the most variable period of the record. Notable anomalies include February 79 (-), January 82 (-), December 80 (-), March 66 (+), February 77 (+), January 77 (+), and January 81 (+). There is no significant long-term trend in the seasonal average temperature data for the division.

NOAA Observation Sites: Major observation sites within this division are: Gulkana, and Tonsina.

#### 4.2.5: Division 5: COOK INLET

Physical Geography: This division includes the western Kenai Peninsula as well as the area between the north coast of Cook Inlet, the Chugach Mountains and the foothills of the southern Alaska Range. Topography ranges from the fjord and tidal flats of Cook Inlet to the broad valleys of the Matanuska and Susitna Rivers. The division is sheltered from the open Gulf of Alaska by the Kenai Peninsula. To the west, the Alaska Range shelters the division from the Bering Sea storms.

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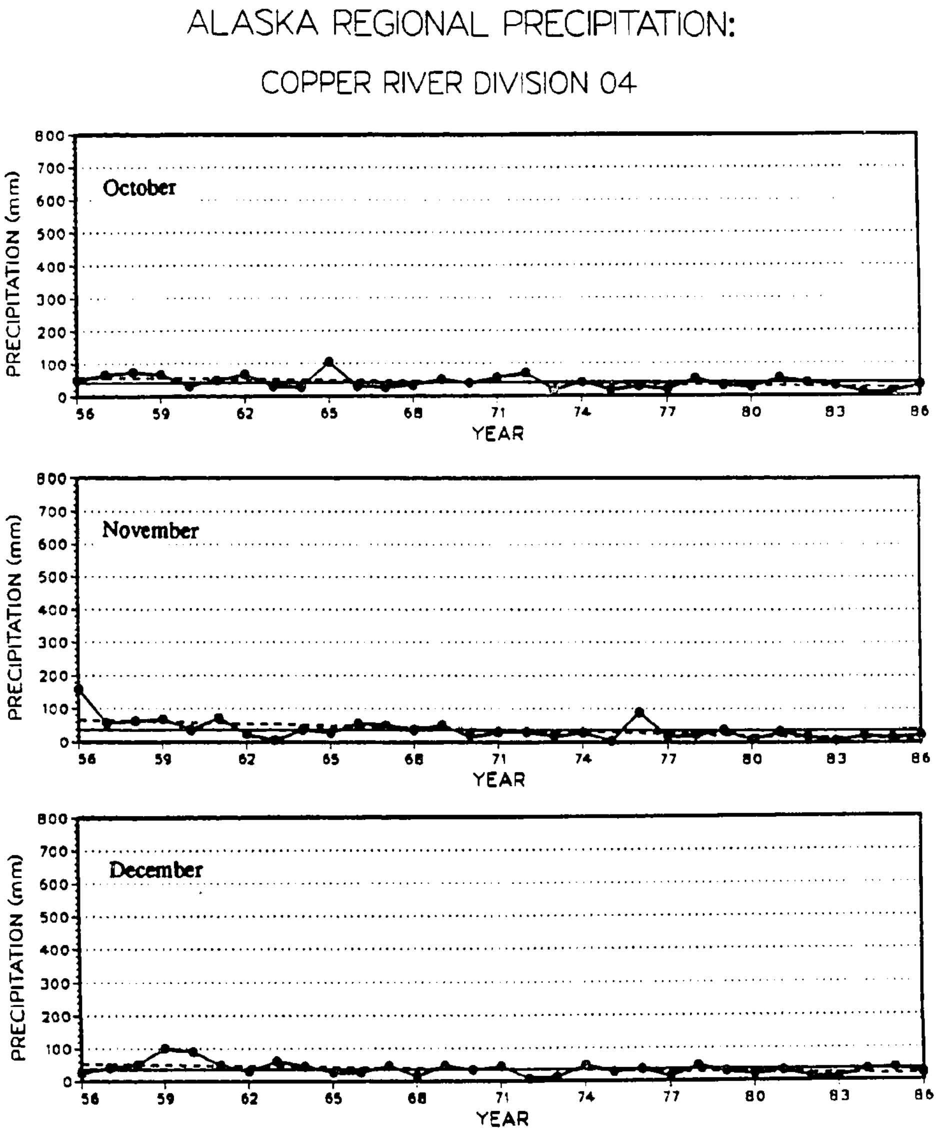


**Figure 4.14** Copper River Division 4 monthly mean precipitation- 1956 to 1986 (winter months). year (x-axis) is the actual date of the data, not the winter season date; solid line with points indicated: data, solid line: thirty-year mean data value for month's data depicted, dashed line: trend (linear least squares fit to data); units are *mm*.

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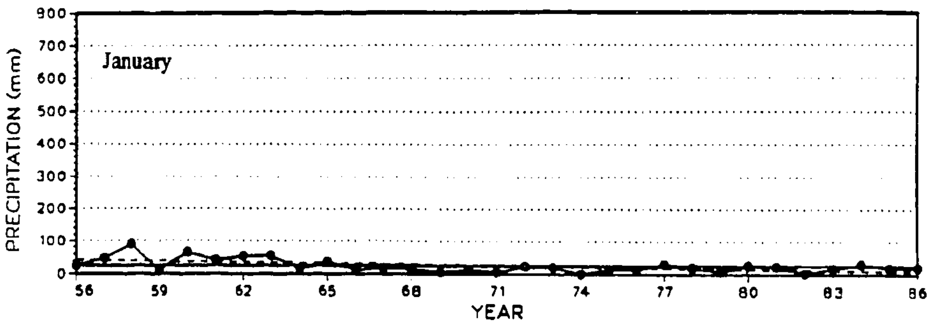


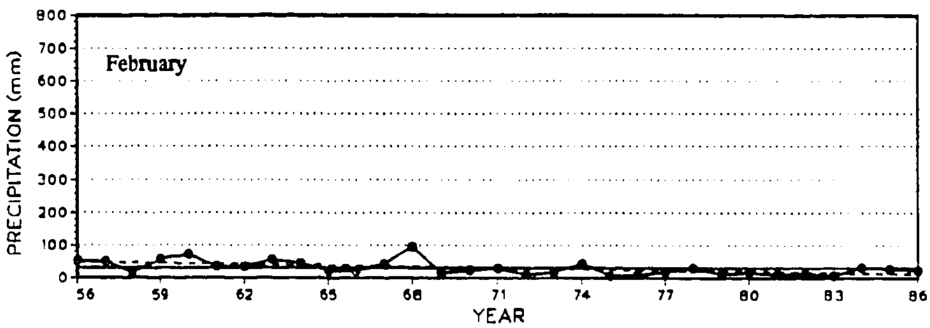


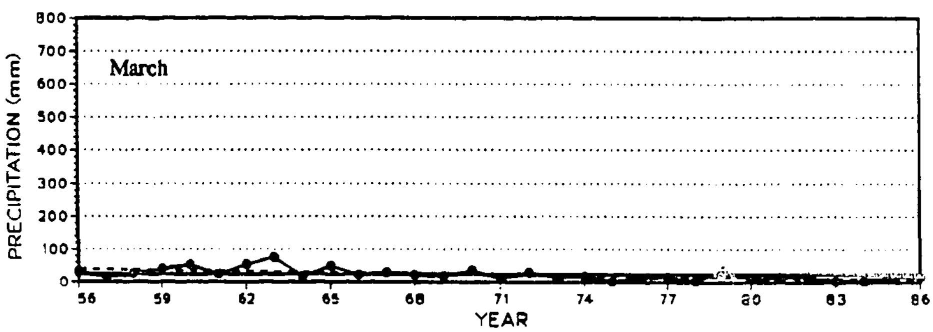


**Figure 4.14cont'd** Copper River Division 4 monthly mean precipitation-1956 to 1986 (winter months). units are *mm*.

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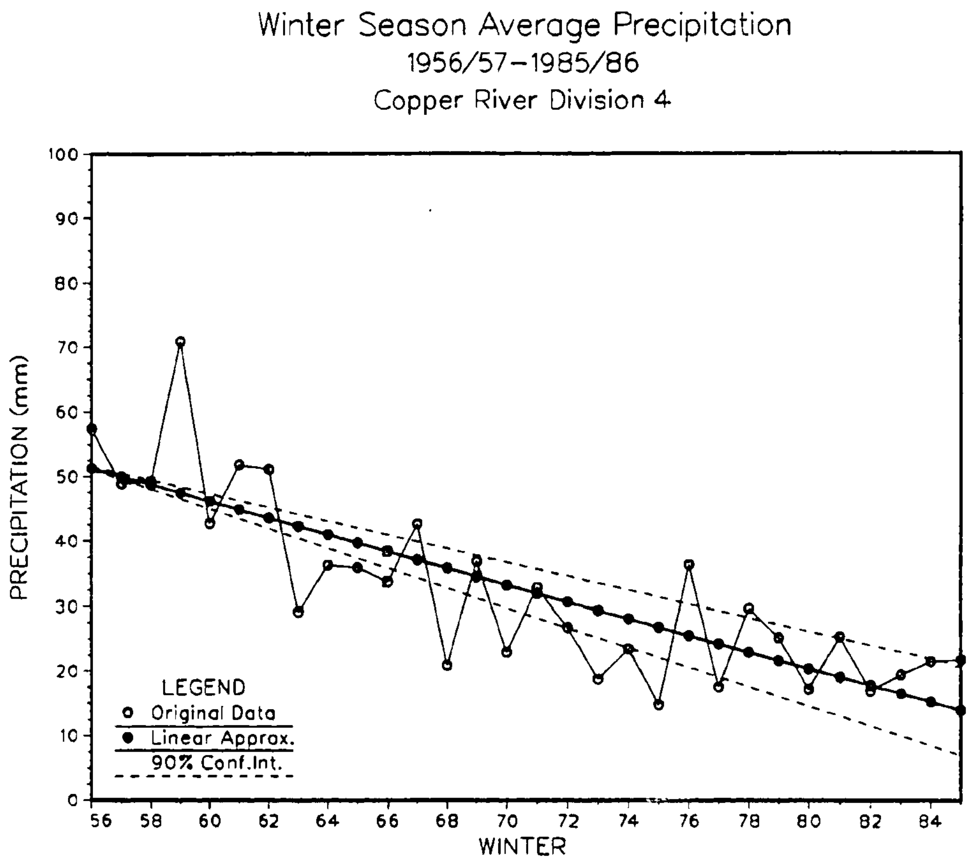


**Figure 4.15** Copper River Division 4 Winter Season average precipitation- Winter 1956/57 to 1985/86. winter season data is an average of the six winter months' (October, November, December, January, February, and March) monthly mean data; units are *mm*.

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**Table 4.4a,b** Copper River Division 4 monthly mean temperature and precipitation. Winter Season extremes (1956/57 to 1985/86) (a) monthly mean temperature, (b) monthly mean precipitation.

**a** Monthly Mean Temperature Statistics: Copper River Division Winter Season 1956-1986

| Month | Max. T | Min. T | Mean T |
|---|---|---|---|
| Oct. | 0.8°$C$ | -7.1°$C$ | -3.1°$C$ |
| Nov. | -5.9 | -20.4 | -13.4 |
| Dec. | -9.7 | -32.0 | -18.6 |
| Jan. | -8.1 | -30.0 | -19.5 |
| Feb. | -6.8 | -27.3 | -14.9 |
| Mar. | -1.7 | -15.6 | -9.6 |

**b** Monthly Mean Precipitation Statistics: Copper River Division Winter Season 1956-1986

| Month | Max. P | Min. P | Mean P |
|---|---|---|---|
| Oct. | 105$mm$ | 11 | 42 |
| Nov. | 158 | 5 | 38 |
| Dec. | 100 | 7 | 36 |
| Jan. | 90 | 1 | 25 |
| Feb. | 95 | 6 | 30 |
| Mar. | 75 | 2 | 24 |

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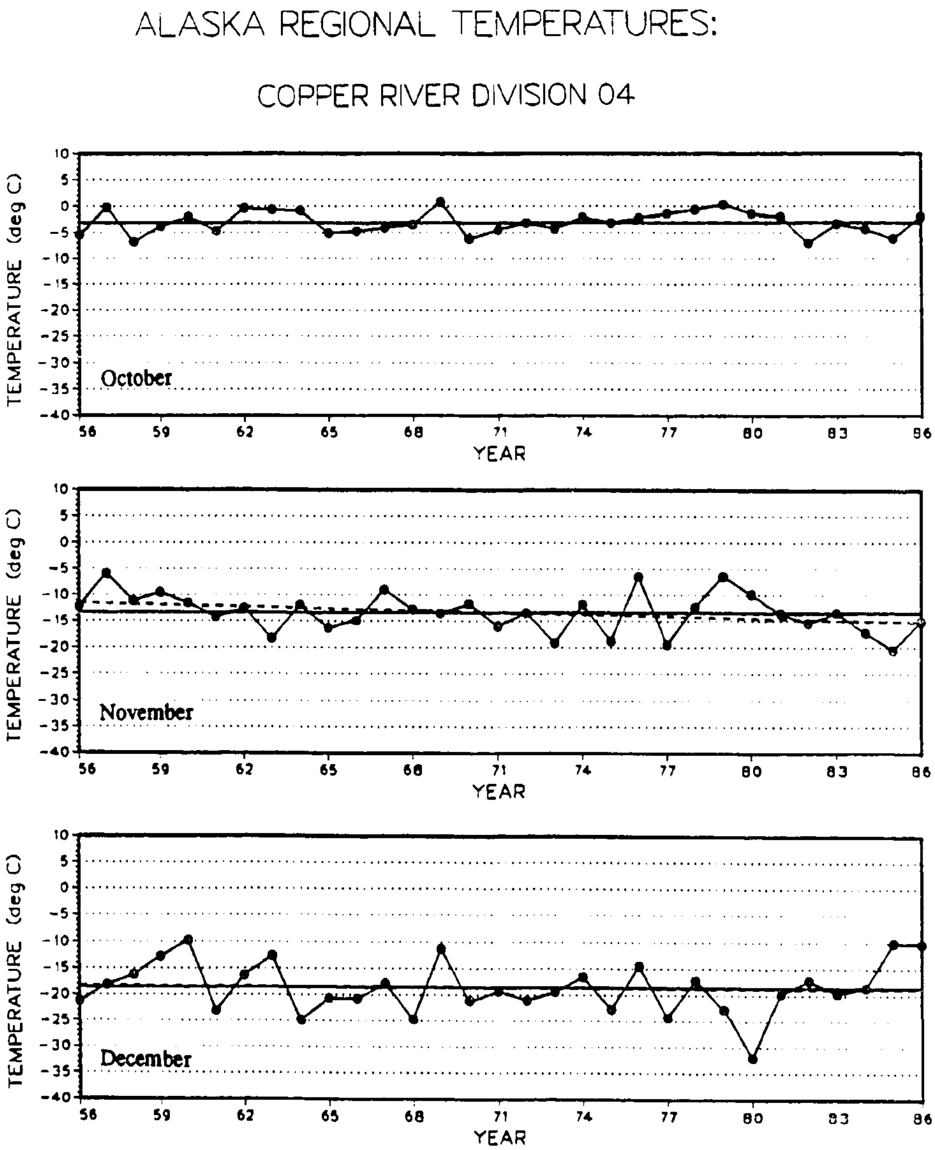


**Figure 4.16** Copper River Division 4 monthly average temperatures-1956 to 1986 (winter months). year (x-axis) is the actual date of the data, not the winter season date: solid line with points indicated: data, solid line: thirty-year mean data value for month's data depicted, dashed line: trend (linear least squares fit to data); units are $^{\circ}C$.

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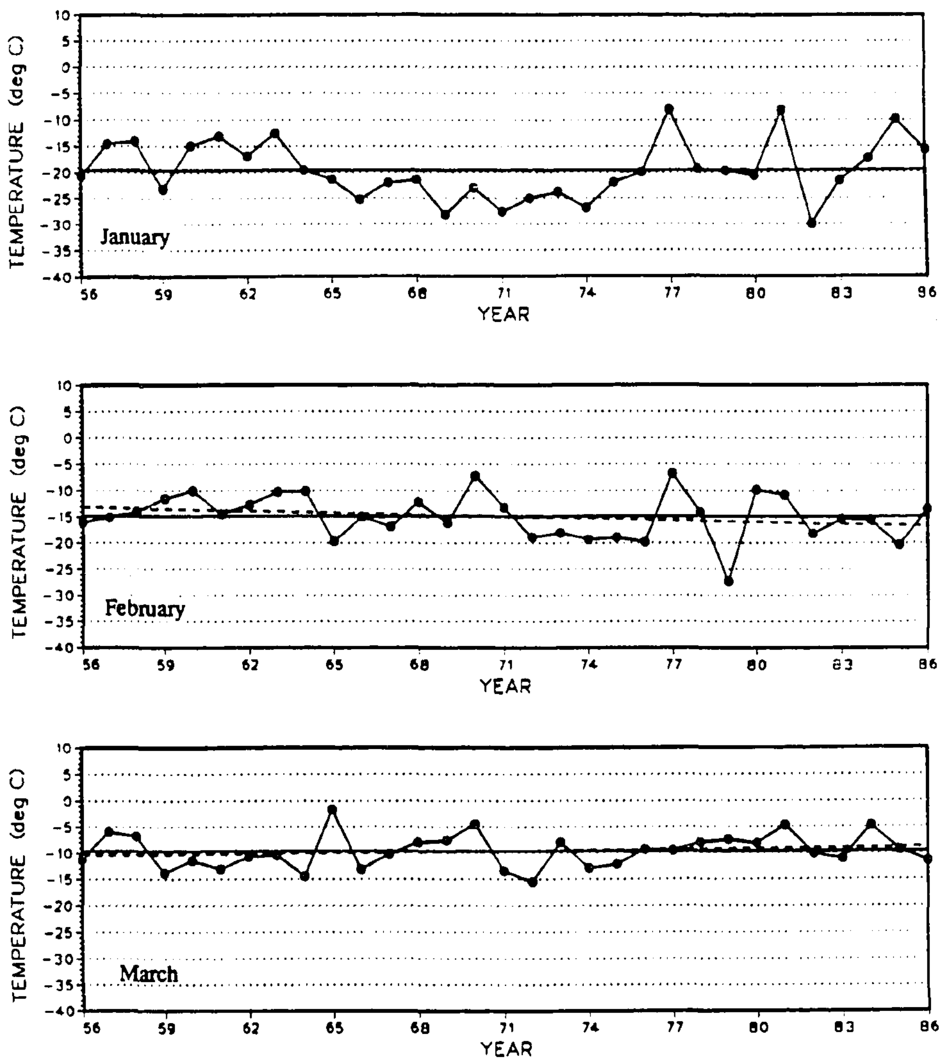


**Figure 4.16cont'd** Copper River Division 4 monthly average temperatures-1956 to 1986 (winter months). units are $^\circ C$.

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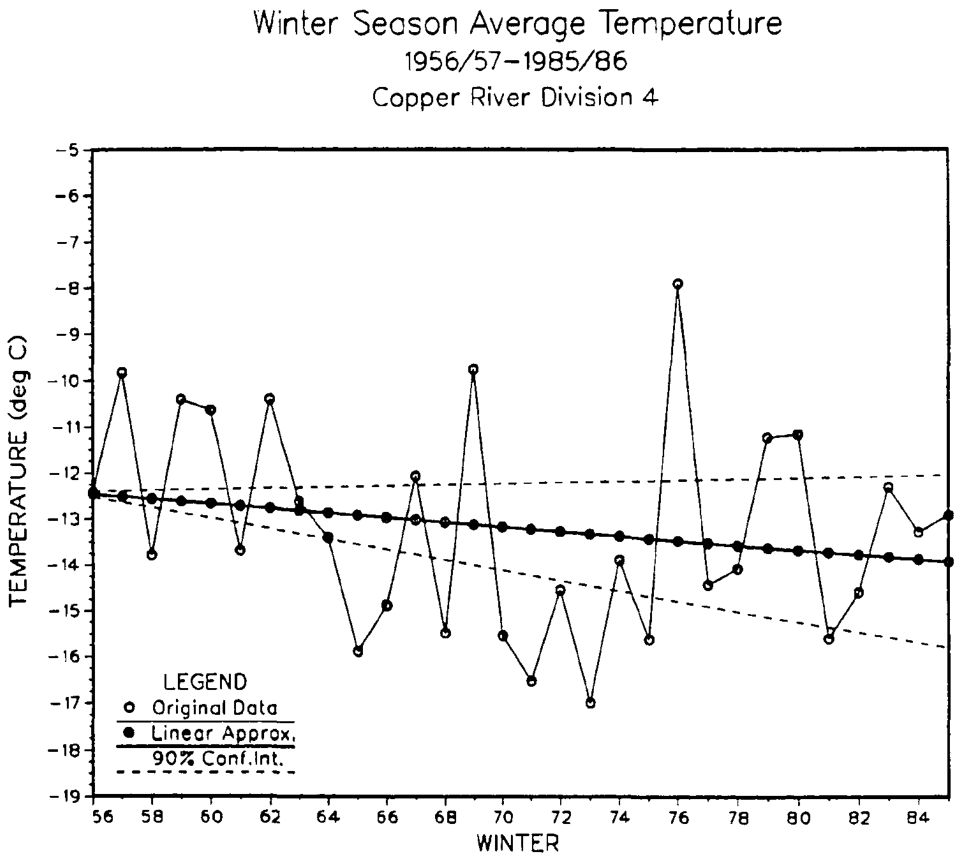


**Figure 4.17** Copper River Division 4 Winter Season average temperatures- Winter 1956/57 to 1985/86. winter season data is an average of the six winter months' (October, November, December, January, February, and March) monthly mean data; units are $^{\circ}C$.

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Climate: Despite its sheltered location, the climate of Cook Inlet is still primarily maritime. Only the interior river valleys of the division can be characterized as having a somewhat continental climate. Winter precipitation is a mixture of rain, sleet, drizzle, and snow. Totals are large but lower than those recorded along the open coastline. Precipitation amounts (Figs. 4.18 and 4.19, Table 4.5b) range from an average of $64mm$ in October to $30mm$ in March. The most variable month in terms of interannual fluctuations is November. The maximum monthly total for November was $171mm$ in 1979 and the minimum monthly total was $7mm$ in 1963. The long-term trend fit to the precipitation record suggests no change over the last thirty years. However, there was an extended dry period from 1964-1979 in January. November and December records also indicate a somewhat shorter dry episode during the same period. Shorter-term anomalous periods include: November 1979 (+), January 81 (+) and November 63 (-). There is no significant long-term trend in the seasonal average precipitation data for the division.

Temperatures (Figs. 4.20 and 4.21, Table 4.5a) are more variable than those of the true gulf coast divisions due to the more-inland nature of the division. Thirty-year monthly mean values range from $0.6°C$ in October to $-10.2°C$ in January. October is the only month with a long-term mean above the freezing mark. The largest interannual fluctuations in monthly mean temperatures occur in December, January and February. December, January, and March also show a warming trend over the thirty-year study period. The longest period of below normal temperatures occurs from 1965 to 1976 in January. December and February temperatures show a similar episode but it is not as extreme nor as lengthy. As in the coastal division records, the cold period is preceded by several seasons of above normal temperatures and followed by the most variable seasons. Individual anomalous months include: December 80 (-), February 79 (-), January 77 (+), January 81 (+), January 85 (+), December 69 (+), February 77 (+), December 60 (+), and December 63 (+). There is no significant long-term trend in the seasonal average temperature data for the division.

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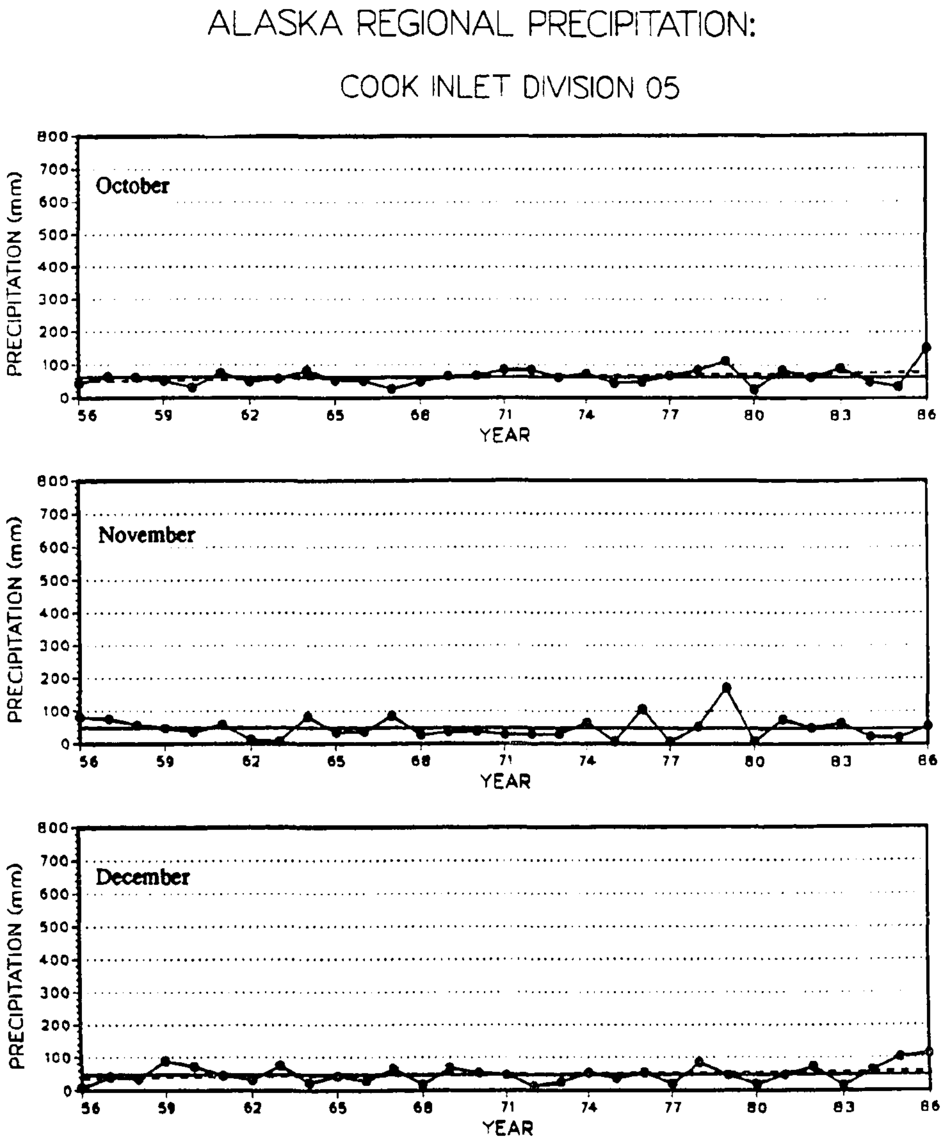


**Figure 4.18** Cook Inlet Division 5 monthly mean precipitation- 1956 to 1986 (winter months). year (x-axis) is the actual date of the data, not the winter season date; solid line with points indicated: data, solid line: thirty-year mean data value for month's data depicted, dashed line: trend (linear least squares fit to data); units are *mm*.

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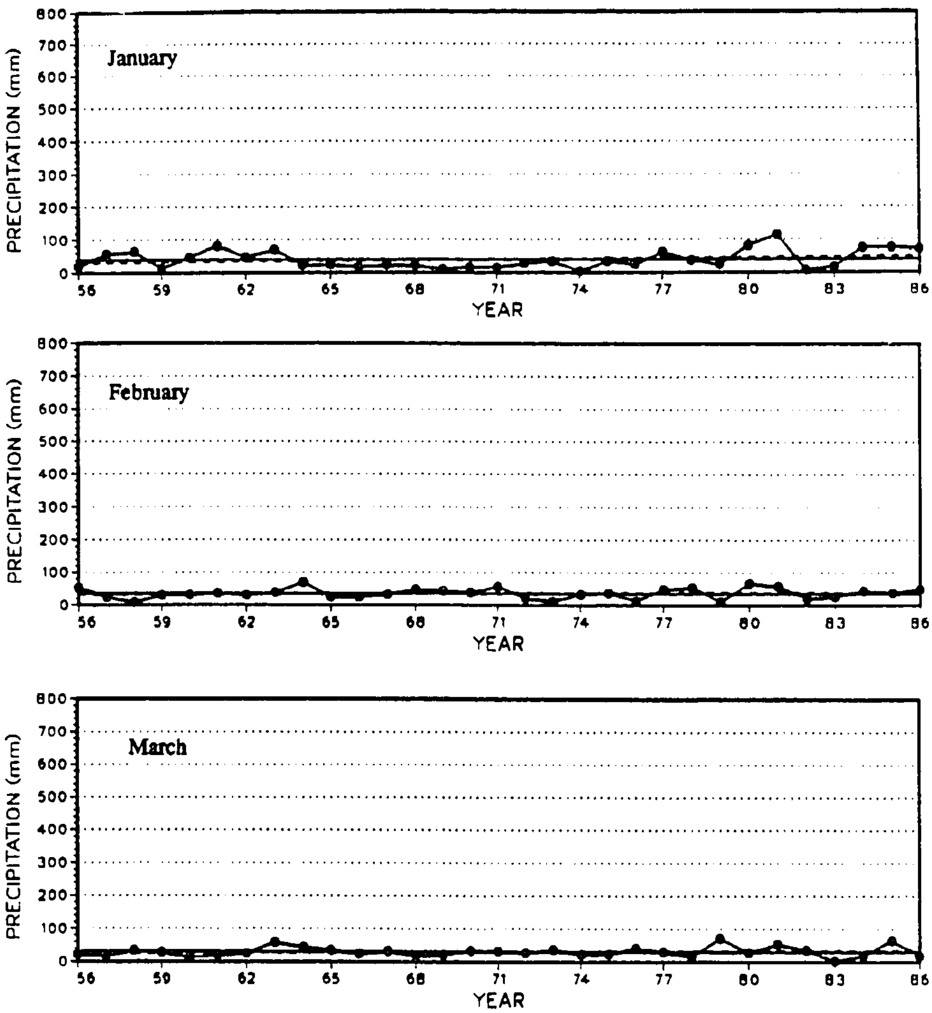


**Figure 4.18cont'd** Cook Inlet Division 5 monthly mean precipitation-1956 to 1986 (winter months). units are *mm*.

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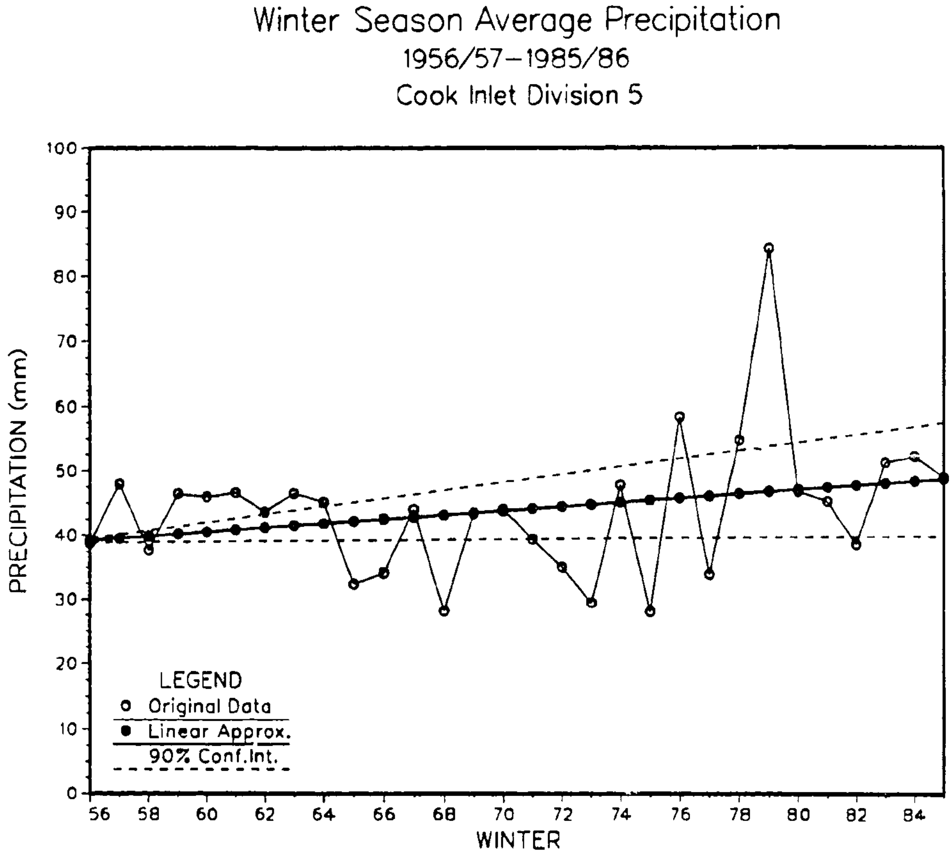


**Figure 4.19** Cook Inlet Division 5 Winter Season average precipitation- Winter 1956/57 to 1985/86. winter season data is an average of the six winter months' (October, November, December, January, February, and March) monthly mean data; units are *mm*.

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**Table 4.5a,b** Cook Inlet Division 5 monthly mean temperature and precipitation. Winter Season extremes (1956/57 to 1985/86) (a) monthly mean temperature, (b) monthly mean precipitation.

**a**

| Monthly Mean Temperature Statistics: Cook Inlet Division Winter Season 1956-1986 | | | |
|---|---|---|---|
| Month | Max. T | Min. T | Mean T |
| Oct. | 3.8°$C$ | -3.7°$C$ | 0.6°$C$ |
| Nov. | 0.5 | -11.4 | -6.3 |
| Dec. | -2.4 | -18.8 | -9.8 |
| Jan. | -0.3 | -18.3 | -10.2 |
| Feb. | -0.4 | -15.6 | -7.9 |
| Mar. | 1.0 | -10.3 | -4.6 |

**b**

| Monthly Mean Precipitation Statistics: Cook Inlet Division Winter Season 1956-1986 | | | |
|---|---|---|---|
| Month | Max. P | Min. P | Mean P |
| Oct. | 112$mm$ | 26 | 64 |
| Nov. | 171 | 7 | 49 |
| Dec. | 101 | 9 | 49 |
| Jan. | 114 | 4 | 40 |
| Feb. | 70 | 8 | 36 |
| Mar. | 71 | 3 | 30 |

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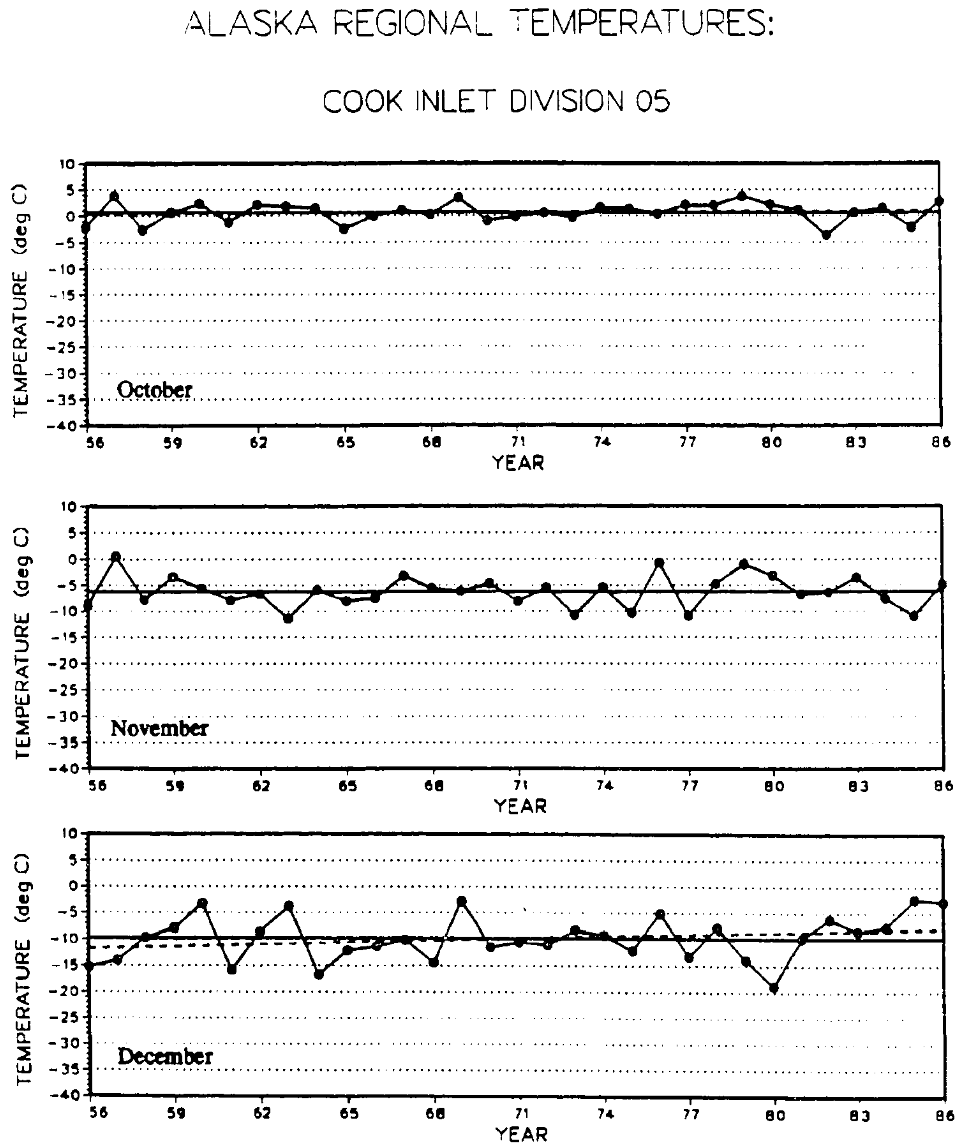


**Figure 4.20** Cook Inlet Division 5 monthly average temperatures-1956 to 1986 (winter months). year (x-axis) is the actual date of the data, not the winter season date; solid line with points indicated: data, solid line: thirty-year mean data value for month's data depicted, dashed line: trend (linear least squares fit to data); units are $^{\circ}C$.

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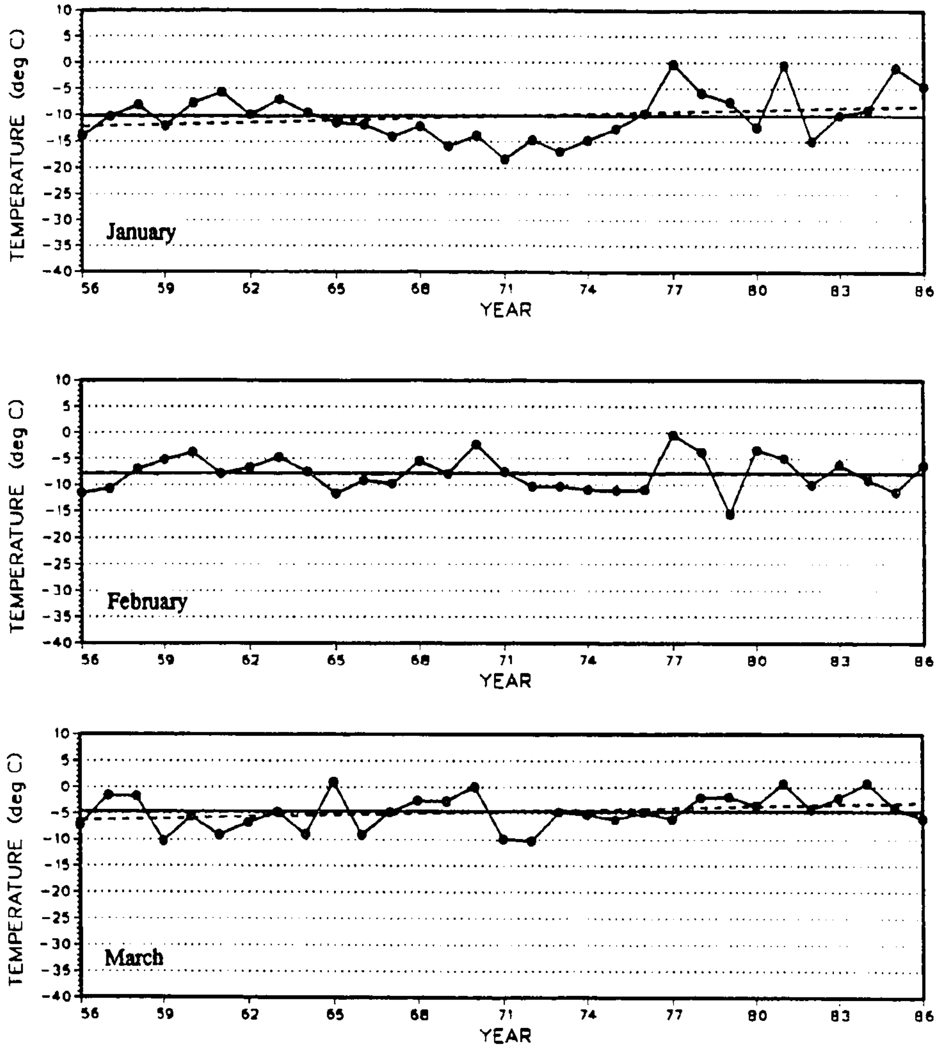


**Figure 4.20cont'd** Cook Inlet Division 5 monthly average temperatures-1956 to 1986 (winter months). units are $^{\circ}C$.

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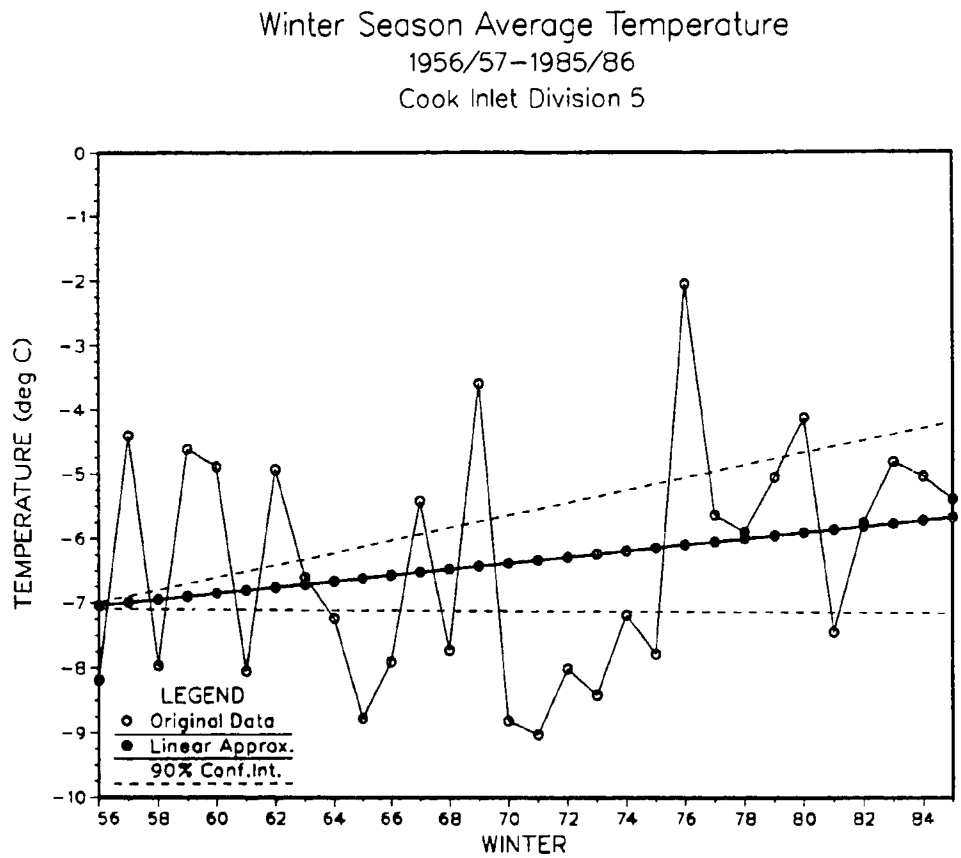


**Figure 4.21** Cook Inlet Division 5 Winter Season average temperatures- Winter 1956/57 to 1985/86. winter season data is an average of the six winter months' (October, November, December, January, February, and March) monthly mean data; units are °$C$.

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NOAA Observation Sites: Major observation sites within this division are: Anchorage, Eklutna, Elmendorf AFB, Palmer, Puntilla, Talkeetna, Wasilla, Homer, Kasilof, Kenai, and Matanuska.

### 4.2.6: Division 6: BRISTOL BAY

Physical Geography: The division is sandwiched along the Bristol Bay between the West Central, Interior, Cook Inlet, and South Coast divisions. Topographic features include the southern flats of the Yukon and Kuskokwim Rivers, the western portion of the Alaska Range, and the tidal flats of Bristol Bay. The eastern boundary of the division is formed by the westernmost extension of the Alaska Range. The mountainous area also includes Lake Iliamna and the volcanoes (Mt.Redoubt and Iliamna– $3000m+$) along the western shore of Cook Inlet. The southern part of the division consists of the central and western Alaska Peninsula, including the Katmai volcanic region. As its name indicates, the division opens southwestward to Bristol Bay and the Bering Sea. Although there is not a direct path for water transfer between the Northeast Pacific and the Bering Sea in the division, the area is influenced by the confluence of the two water bodies. The division marks the southernmost extent of Bering Sea ice during normal years.

Climate: The climate of the division is maritime. The region is exposed to storms generated in the southern Bering Sea and to those in the Northeast Pacific. Winter precipitation may be a mixture of freezing drizzle and fog as well as snow on the delta and Alaska Peninsula. The higher elevations along Cook Inlet receive enough snow to maintain permanent snow fields. Monthly mean precipitation values (Fig.4.22, Table 4.6b) range from $70mm$ in October to $29mm$ in February. The dryest single month was November 1963 with an average of just $3mm$ observed. This contrasts with the October 1969 average value of $119mm$. Interannual variability is low for all of the winter months. The only extended dry period is January 1964-1975. A shorter dry episode occurred from 1972 to 1976 in February. As seen with the other divisions, the most variable period in the record is

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after the 1976 season. There are no distinctly anomalous months. There is no significant long-term trend in the seasonal average precipitation data (Fig. 4.23) for the division.

Average temperatures (Figs. 4.24 and 4.25, Table 4.6a) are similar to those of Cook Inlet. The range is from $0.8°C$ in October to $-9.2°C$ in February. The long-term trend plotted suggests an increase in the December, January and March average values. A smaller increase is indicated in the November record. The last four months of the winter season are the most variable in terms of interannual fluctuations. Again, we see the cold period from 1966- 1976 in the January time series. A similar but less intense cold period exists in the December record during the same period. As with other regions, the cold period is preceded and followed by warmer than normal conditions. However, unlike the other divisions, the interannual variability in this division is large both before and after the cold period. The most pronounced warming trend or above normal period is in December and March from 1980- 1986. Individual anomalies include: January 77 (+), November 63 (-), January 85 (+), February 61 (-), February 84 (-), February 77 (+), March 66 (-), and March 72 (-). There is a significant increasing long-term trend in the seasonal average temperature data for the division.

NOAA Observation Sites: Major observation sites within this division are: Dillingham, Port Heiden, Sparrevohn, Iliamna, King Salmon.

#### 4.2.7: Division 7: WEST CENTRAL

Physical Geography: The West Central division is located along the central Bering Sea coast stretching from $60°N$ to $66°N$ and as far east from the Bering Sea coast as McGrath. It includes the southern Seward Peninsula, Yukon Delta, Kuskokwim Delta, Nunivak Island, and St. Lawrence Island. The topography is that of rolling inland uplands, coastal plains, and flat river deltas. The highest elevations ($1000-1500m$) are found along the eastern Norton Sound, inland from Unalakleet and in the central section of the Seward Peninsula along the continental divide. The division is also

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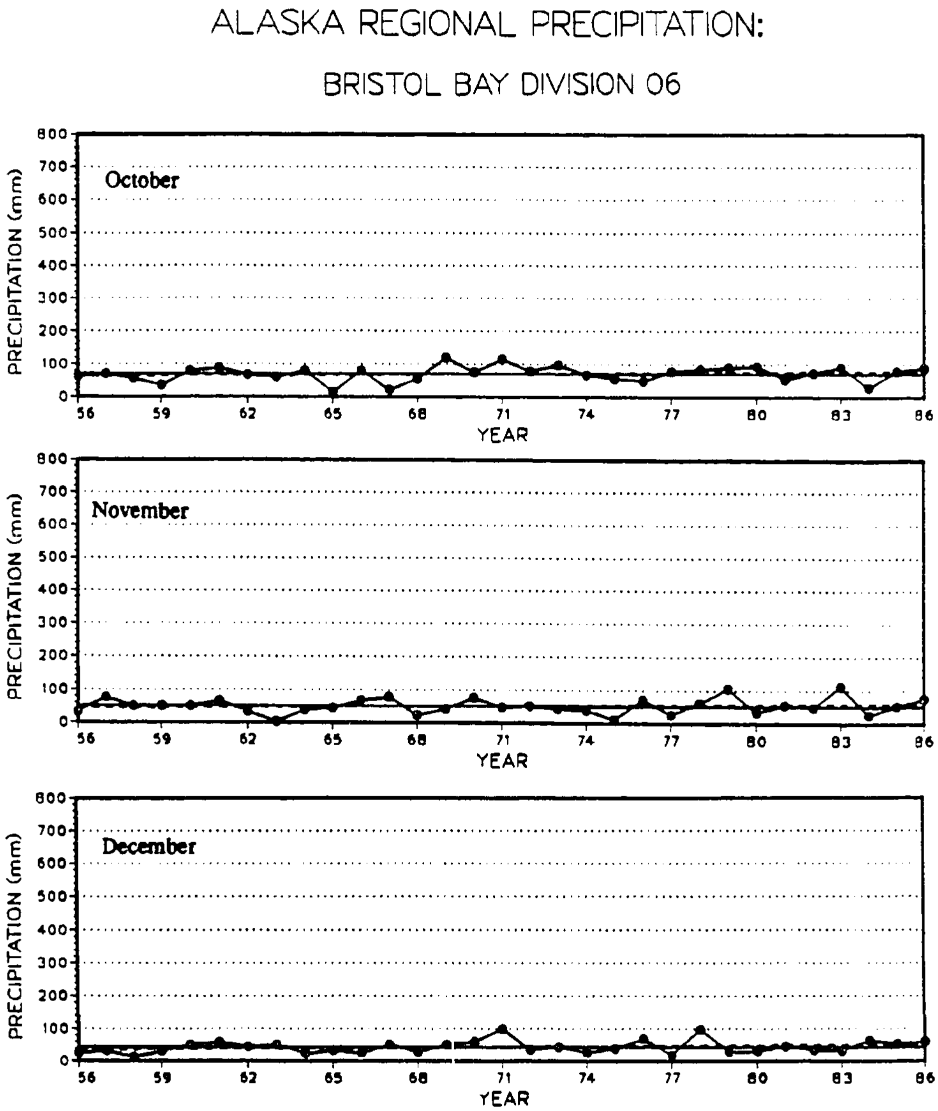


**Figure 4.22** Bristol Bay Division 6 monthly mean precipitation- 1956 to 1986 (winter months). year (x-axis) is the actual date of the data, not the winter season date; solid line with points indicated: data, solid line: thirty-year mean data value for month's data depicted, dashed line: trend (linear least squares fit to data); units are *mm*.

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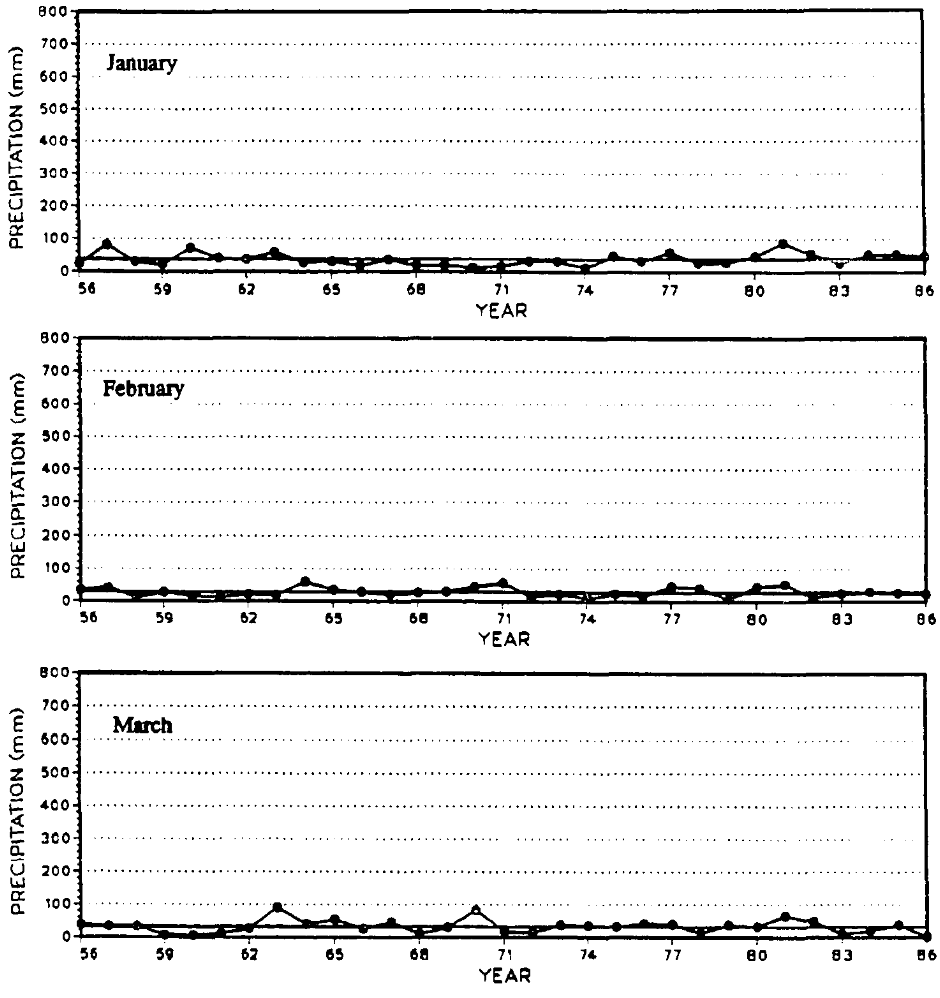


**Figure 4.22cont'd** Bristol Bay Division 6 monthly mean precipitation-1956 to 1986 (winter months). units are *mm*.

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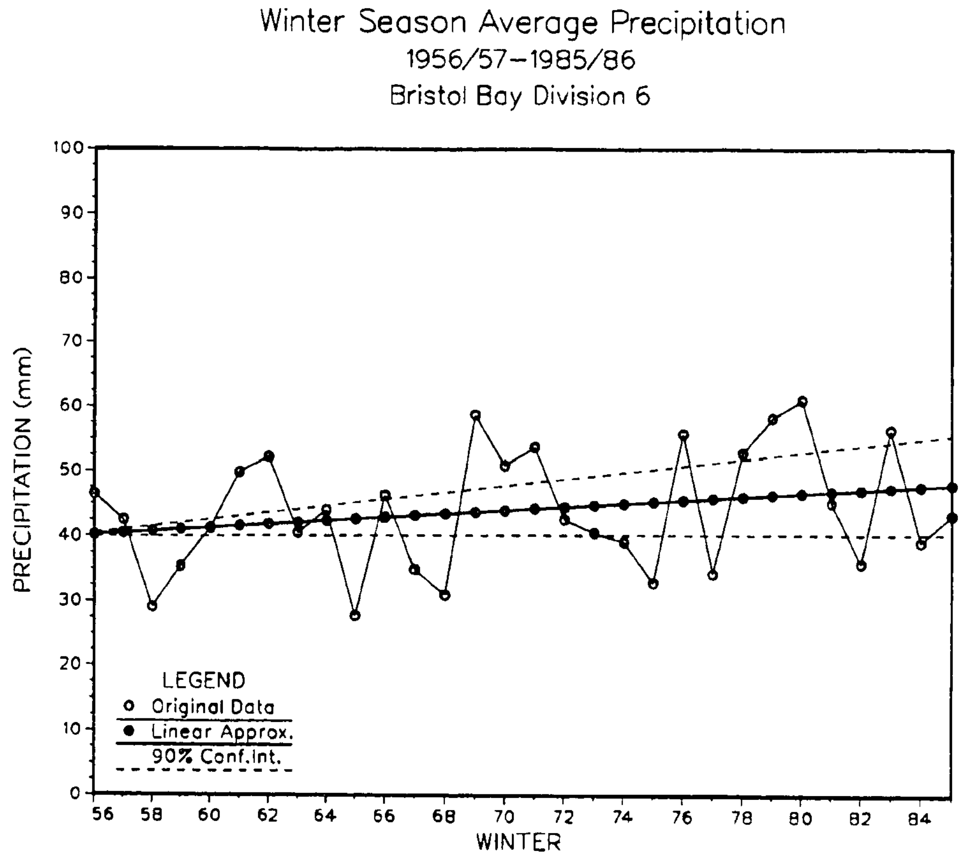


**Figure 4.23** Bristol Bay Division 6 Winter Season average precipitation- Winter 1956/57 to 1985/86. winter season data is an average of the six winter months' (October, November, December, January, February, and March) monthly mean data; units are *mm*.

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**Table 4.6a,b** Bristol Bay Division 6 monthly mean temperature and precipitation. Winter Season extremes (1956/57 to 1985/86) (a) monthly mean temperature, (b) monthly mean precipitation.

**a**

Monthly Mean Temperature Statistics:
Bristol Bay Division
Winter Season 1956-1986

| Month | Max. T | Min. T | Mean T |
|---|---|---|---|
| Oct. | 4.4°$C$ | -2.8°$C$ | 0.8°$C$ |
| Nov. | -0.3 | -11.9 | -4.3 |
| Dec. | 1.6 | -16.4 | -9.0 |
| Jan. | 1.5 | -17.9 | -9.1 |
| Feb. | -0.2 | -18.6 | -9.2 |
| Mar. | 1.0 | -15.3 | -6.0 |

**b**

Monthly Mean Precipitation Statistics:
Bristol Bay Division
Winter Season 1956-1986

| Month | Max. P | Min. P | Mean P |
|---|---|---|---|
| Oct. | 119$mm$ | 15 | 70 |
| Nov. | 114 | 3 | 52 |
| Dec. | 99 | 12 | 44 |
| Jan. | 89 | 12 | 38 |
| Feb. | 61 | 8 | 29 |
| Mar. | 90 | 6 | 33 |

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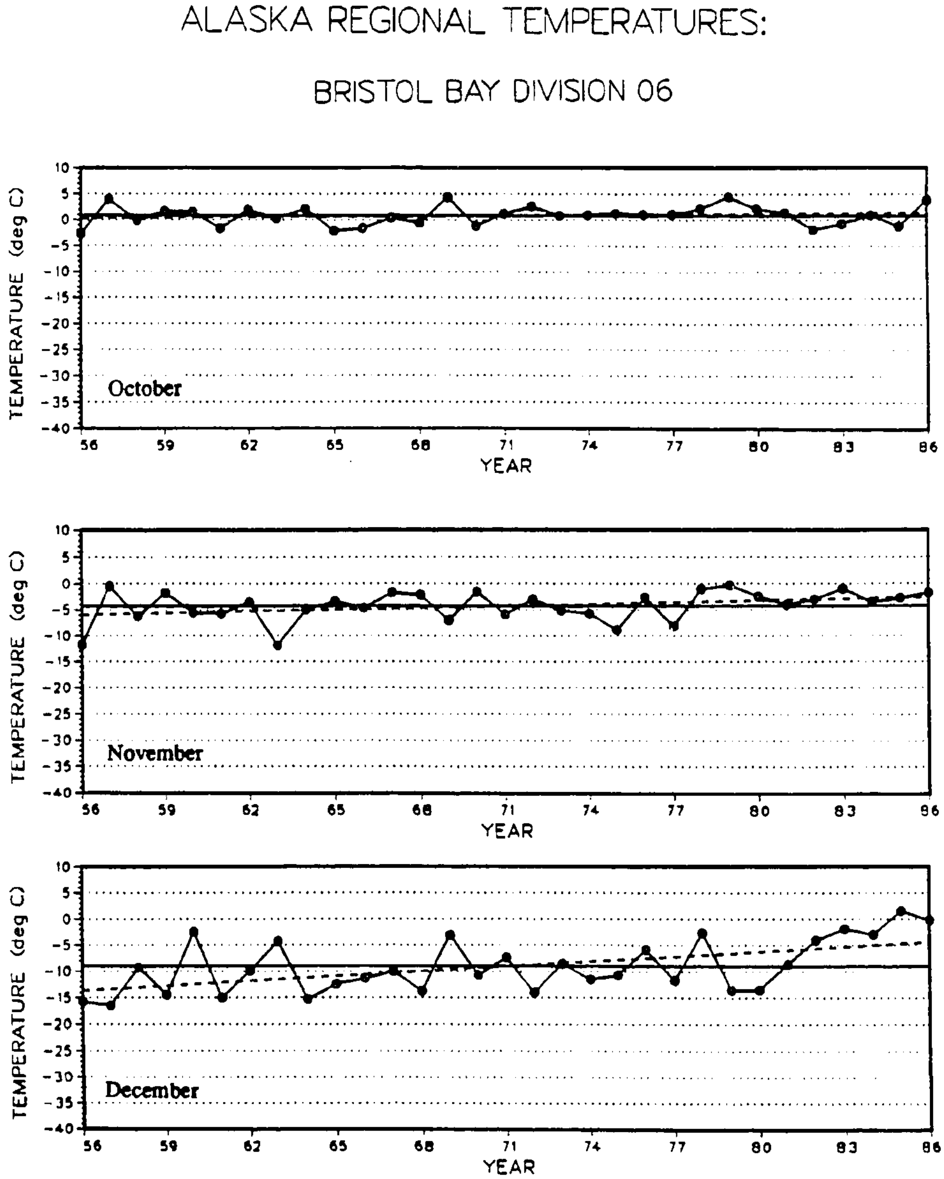


**Figure 4.24** Bristol Bay Division 6 monthly average temperatures-1956 to 1986 (winter months). year (x-axis) is the actual date of the data, not the winter season date; solid line with points indicated: data, solid line: thirty-year mean data value for month's data depicted, dashed line: trend (linear least squares fit to data); units are $^{\circ}C$.

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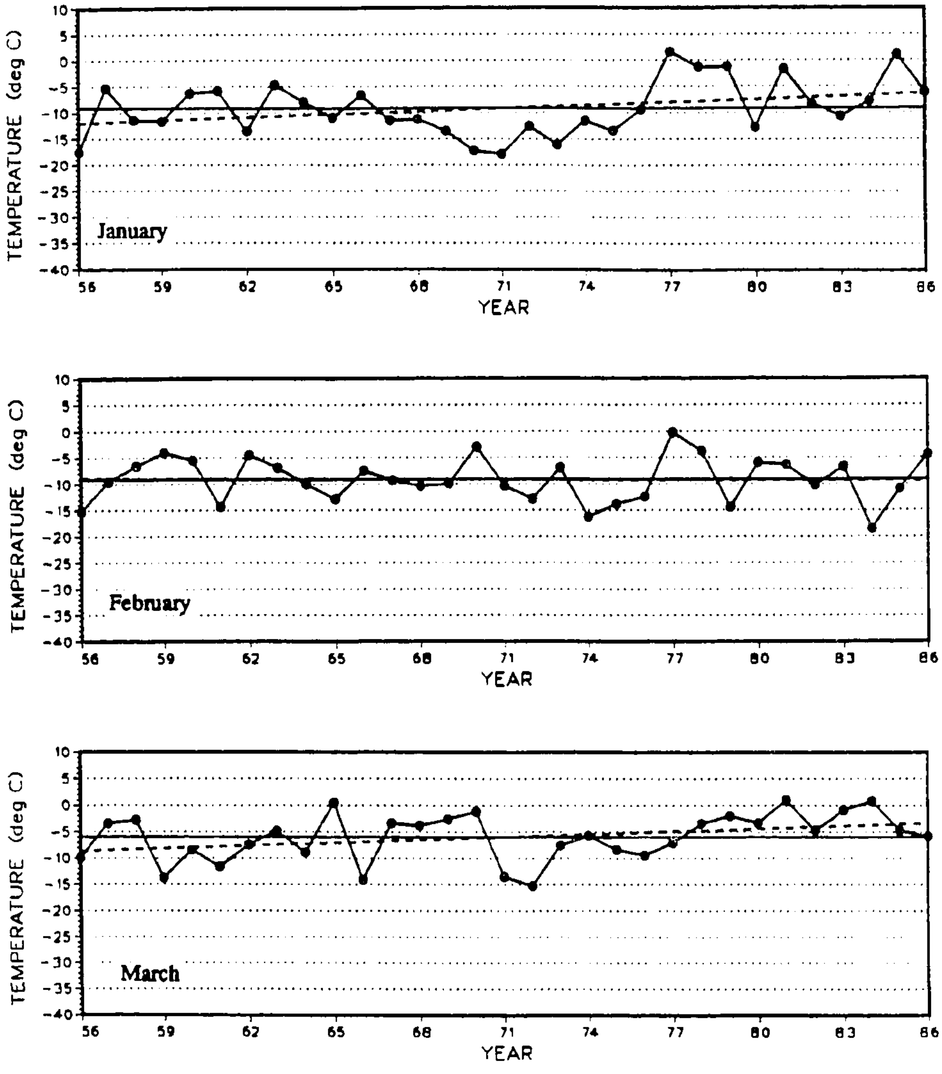


**Figure 4.24cont'd** Bristol Bay Division 6 monthly average temperatures-1956 to 1986 (winter months). units are °$C$.

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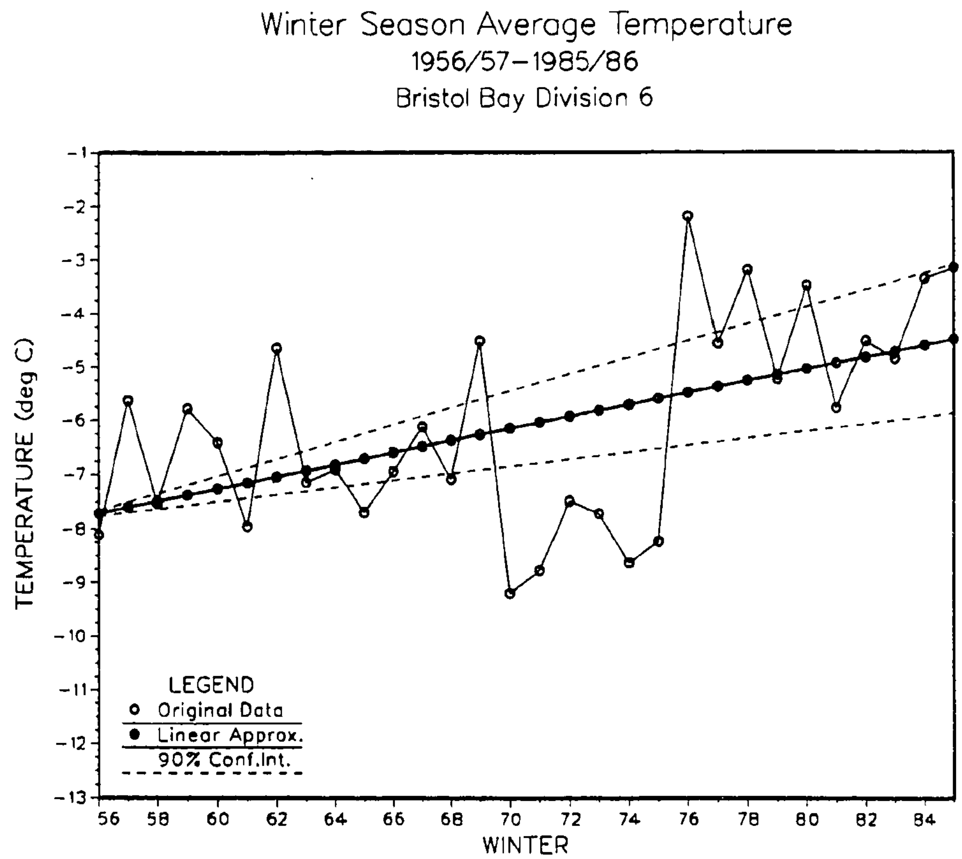


**Figure 4.25** Bristol Bay Division 6 Winter Season average temperatures- Winter 1956/57 to 1985/86. winter season data is an average of the six winter months' (October, November, December, January, February, and March) monthly mean data; units are $^{\circ}C$.

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characterized by terrain resulting from discontinuous permafrost. The major rivers in the division are the Yukon and Kuskokwim which drain into the Bering Sea near Emmonak and Bethel, respectively. Winter season ice cover on the Bering Sea varies from year to year (Webster, 1981). However, in all winter seasons, this ice cover inhibits heat flux from the Bering Sea into the atmosphere, thereby reducing the moderating effect of the ocean upon the climate of the West Central Division (Fathauer, pers. comm.). Winter storms moving across the partially ice-covered Bering Sea from Asia or across the Seward Peninsula from the Chukchi Sea produce most of the winter precipitation in the division. The lack of a protective barrier also leaves the coastline unprotected from the bitter winds which accompany the winter storms. Fog is common during stormy weather.

Climate: The climate of the division is a mixture of transitional and arctic. As there are no great mountain barriers to obstruct the flow of moisture from the ocean, precipitation exclusively orographic in nature. Although most of the precipitation falls in the form of snow, it is not as heavy as in the more southern divisions because the sea ice-covered Bering Sea is not as good a source of moisture as the comparatively warmer Gulf of Alaska waters. Mean monthly values range (Fig. 4.26, Table 4.7b) from $40mm$ in October to $17mm$ in February. There is very little interannual variability evident during the thirty-year study. The longest wet period occurred from 1970 to 1973 in February. The longest dry period occurred from 1974-1978 in January. The most extreme individual months in the winter record are December 71 (+), December 78 (+), and November 79 (+). There is no significant long-term trend in the seasonal average precipitation data (Fig. 4.27) for the division.

The transitional and arctic characteristics of this region are reflected in the mean temperature records. Temperatures (Figs. 4.28 and 4.29, Table 4.7a) are much lower than those of the southern coastal regions. They range from a mean value of $-1.8°C$ in October to $-14.9°C$ in February. October is the only month to have a one-season monthly mean temperature above $0°C$. Interannual variability is greatest in December, January, February, and March. The longest period of below normal temperatures occurred from 1970-1976 during January. The most extended periods of above

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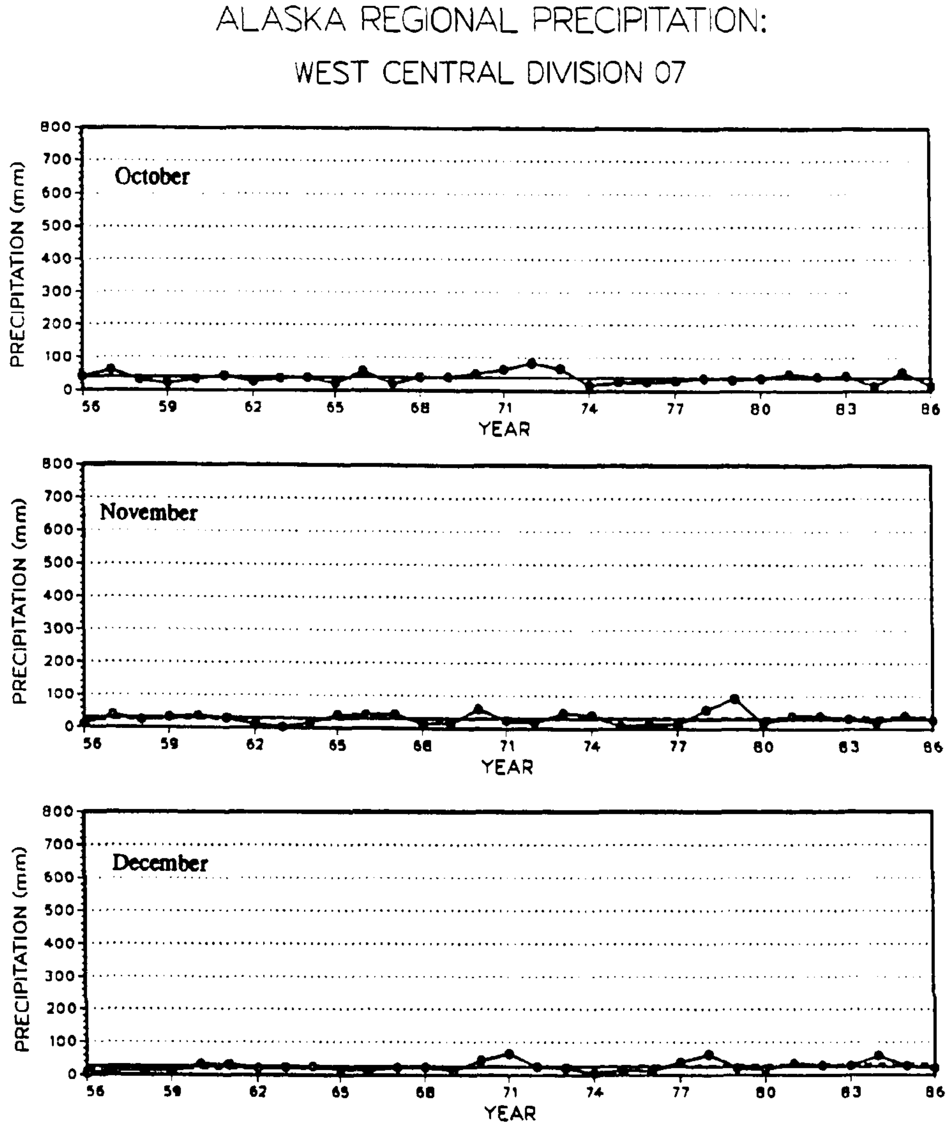


**Figure 4.26** West Central Division 7 monthly mean precipitation- 1956 to 1986 (winter months). year (x-axis) is the actual date of the data, not the winter season date; solid line with points indicated: data, solid line: thirty-year mean data value for month's data depicted, dashed line: trend (linear least squares fit to data); units are *mm*.

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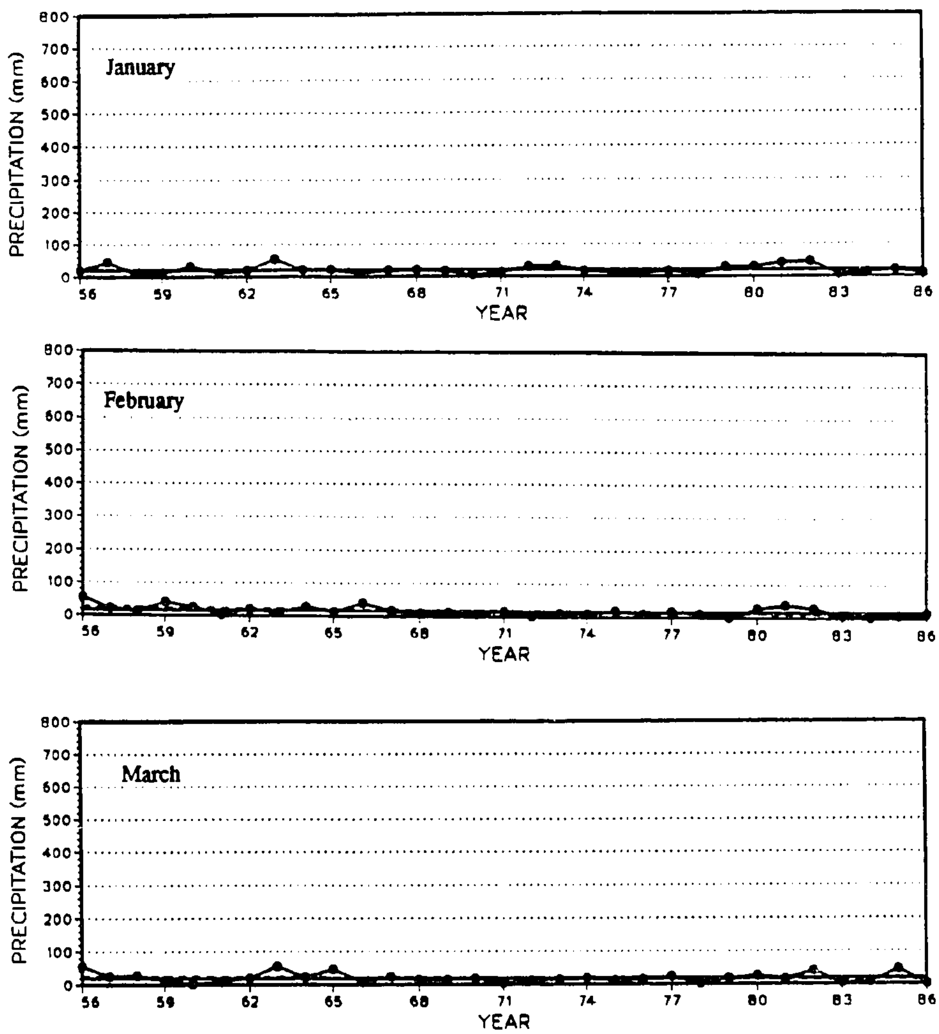


**Figure 4.26cont'd** West Central Division 7 monthly mean precipitation-1956 to 1986 (winter months). units are *mm*.

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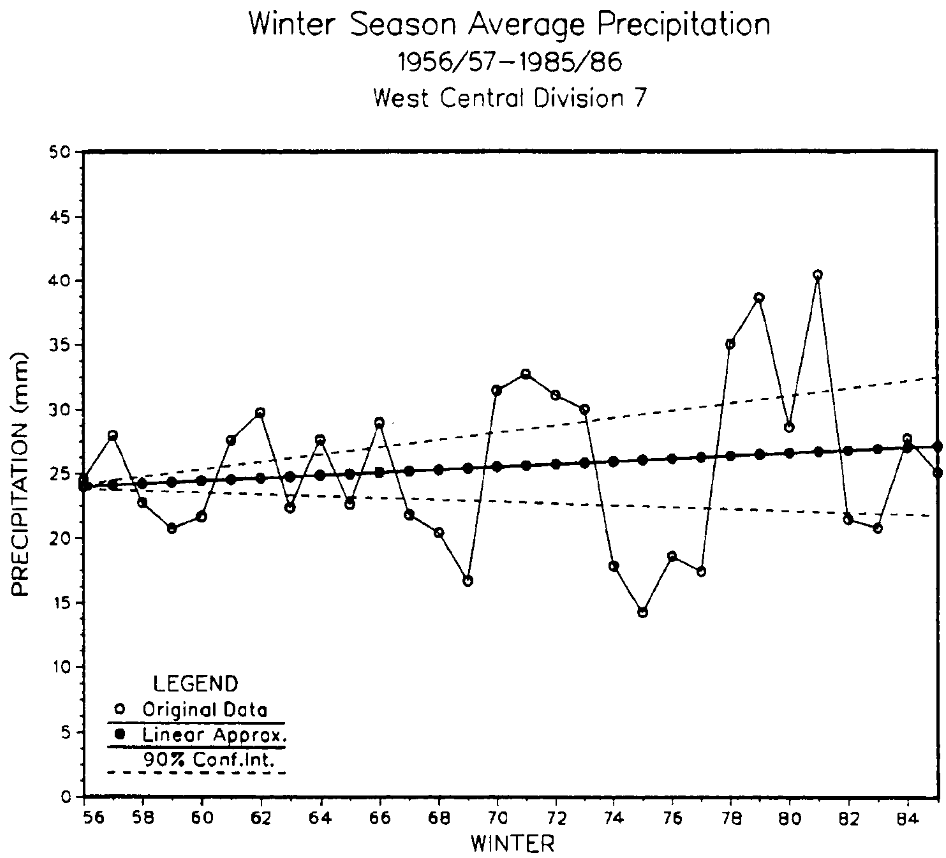


**Figure 4.27** West Central Division 7 Winter Season average precipitation- Winter 1956/57 to 1985/86. winter season data is an average of the six winter months' (October, November, December, January, February, and March) monthly mean data; units are *mm*.

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**Table 4.7a,b** West Central Division 7 monthly mean temperature and precipitation. Winter Season extremes (1956/57 to 1985/86) (a) monthly mean temperature, (b) monthly mean precipitation.

| a<br>Monthly Mean Temperature Statistics:<br>West Central Division<br>Winter Season 1956-1986 | | | |
|---|---|---|---|
| Month | Max. T | Min. T | Mean T |
| Oct. | 1.7°$C$ | -4.2°$C$ | -1.8°$C$ |
| Nov. | -4.3 | -14.6 | -8.2 |
| Dec. | -5.1 | -21.2 | -14.1 |
| Jan. | -5.9 | -23.0 | -14.3 |
| Feb. | -7.9 | -26.3 | -14.9 |
| Mar. | -6.0 | -20.3 | -12.6 |

| b<br>Monthly Mean Precipitation Statistics:<br>West Central Division<br>Winter Season 1956-1986 | | | |
|---|---|---|---|
| Month | Max. P | Min. P | Mean P |
| Oct. | 84$mm$ | 16 | 40 |
| Nov. | 93 | 3 | 31 |
| Dec. | 65 | 3 | 26 |
| Jan. | 55 | 5 | 21 |
| Feb. | 55 | 1 | 17 |
| Mar. | 56 | 6 | 20 |

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normal temperatures occurred from 1978-1984 in March and from 1981-1986 in December. The linear trend fit to the December time series indicates a warming in monthly mean temperatures over the last thirty years. None of the other monthly records for this division exhibit much indication of long-term change. Individual anomalous months include: December 74 (-), December 79 (-), January 80 (-), February 76 (-), February 84 (-), February 62 (+), March 57(+), December 60 (+), and January 85 (+). There is no significant long-term trend in the seasonal average temperature data for the division.

NOAA Observation Sites: Major observation sites within this division are: Aniak, Bethel, Cape Romanzof, Wales, and Nome.

### 4.2.8: Division 8: INTERIOR BASIN

Physical Geography: The Interior Basin is the largest division in the state. It is bounded on the south by the Alaska Range and the Bristol Bay Division, the east by the Alaska-Canada (ALCAN) border, the north by the Arctic Drainage division,and the west, by the West Central division. The southeastern boundary of the division includes the rim of the Alaska Range with its summits of more than 3500$m$. Among these peaks is the 6000$m$+ Mt. McKinley. Extending north and west from the foothills of the Alaska range are the rolling uplands along the ALCAN (Alaska-Canada) border, and the broad valley created by the Yukon and its tributaries. Thermokarst topography is also evident as the division lies within Alaska's zone of discontinuous permafrost. The Alaska Range provides the major barrier for maritime air flowing inland to the north from the gulf. Because of the height of the mountains, very little moisture actually reaches the interior from the south. The Brooks Range provides a northern shield for the division. Thus, the moisture entering the interior must be transported from the west (Bering Sea) across the state, or from the southeast (Canada) around the great coastal ranges. Ice fog often forms near settlements during cold weather (Oliver and Oliver,

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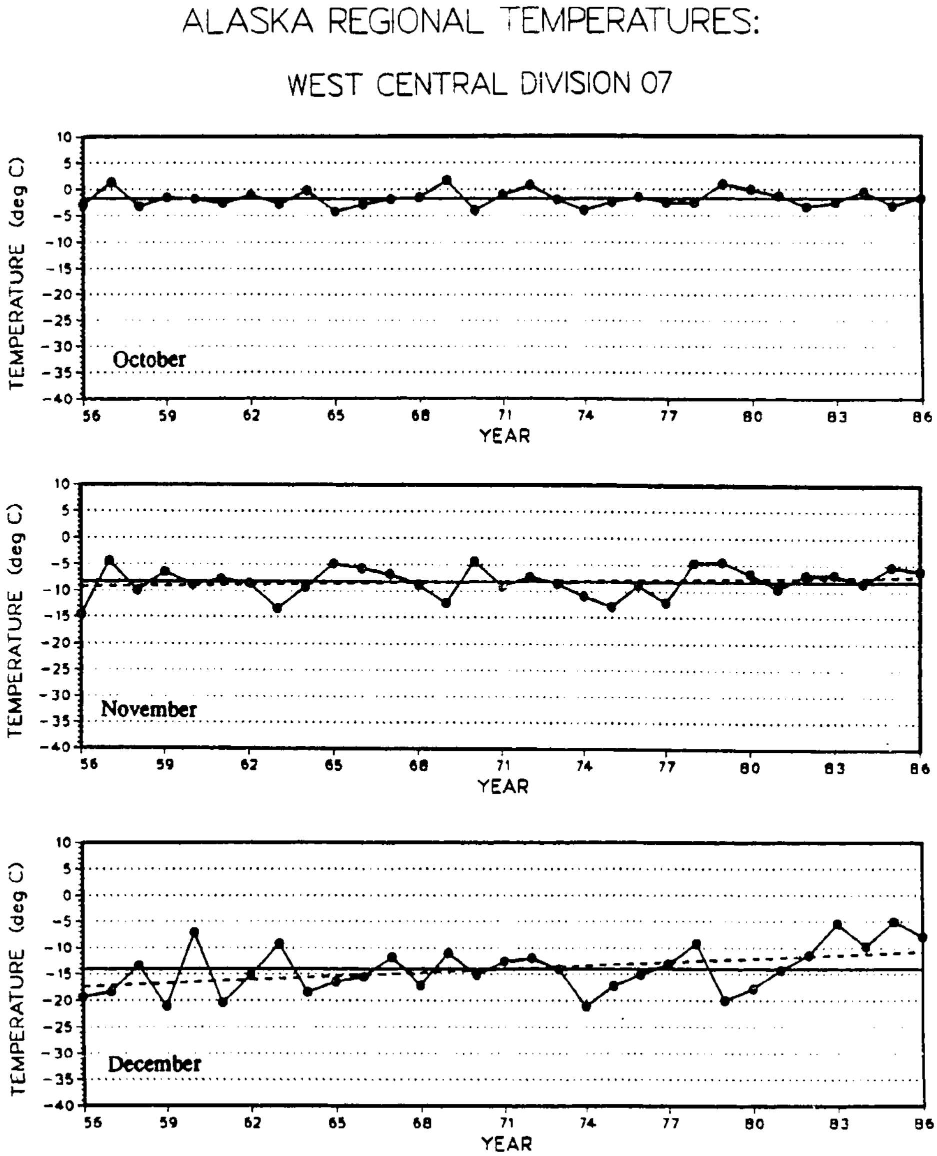


**Figure 4.28** West Central Division 7 monthly average temperatures-1956 to 1986 (winter months). year (x-axis) is the actual date of the data, not the winter season date; solid line with points indicated: data, solid line: thirty-year mean data value for month's data depicted, dashed line: trend (linear least squares fit to data); units are °$C$.

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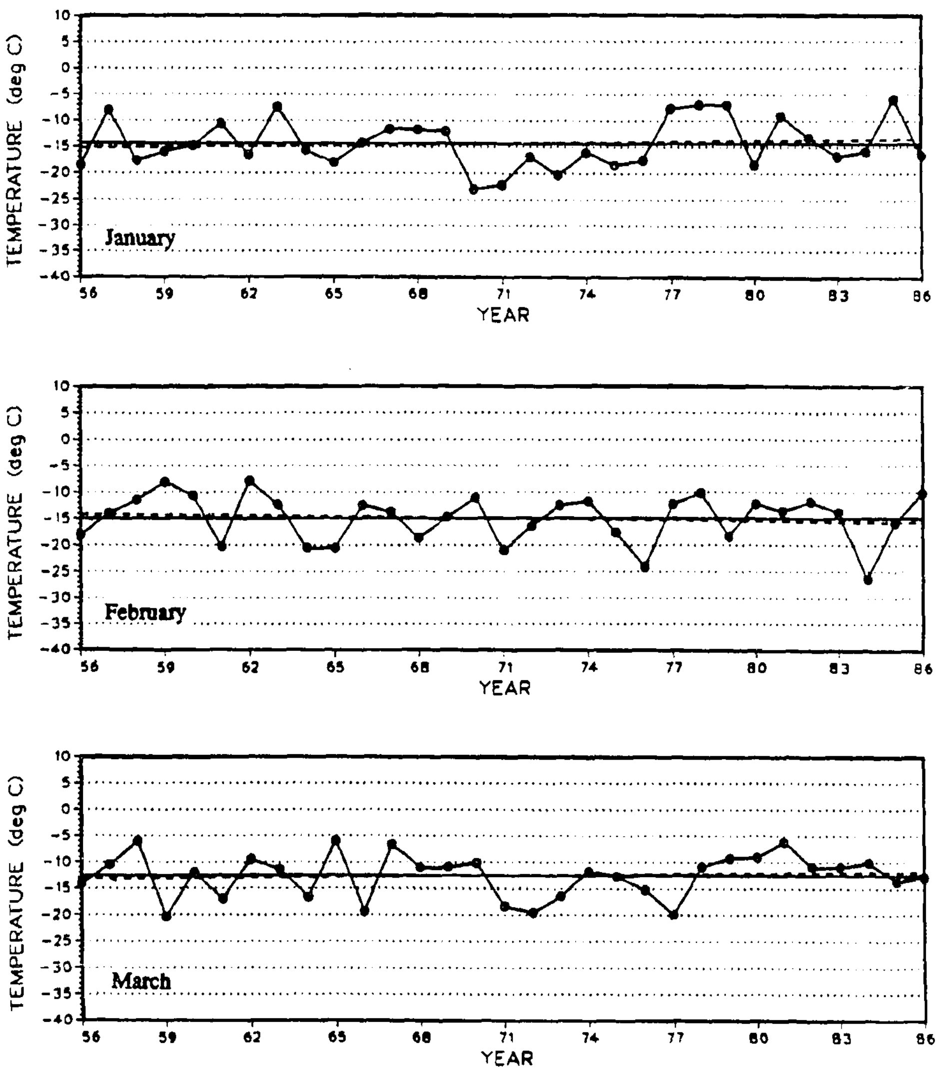


**Figure 4.28cont'd** West Central Division 7 monthly average temperatures-1956 to 1986 (winter months). units are $^{\circ}C$.

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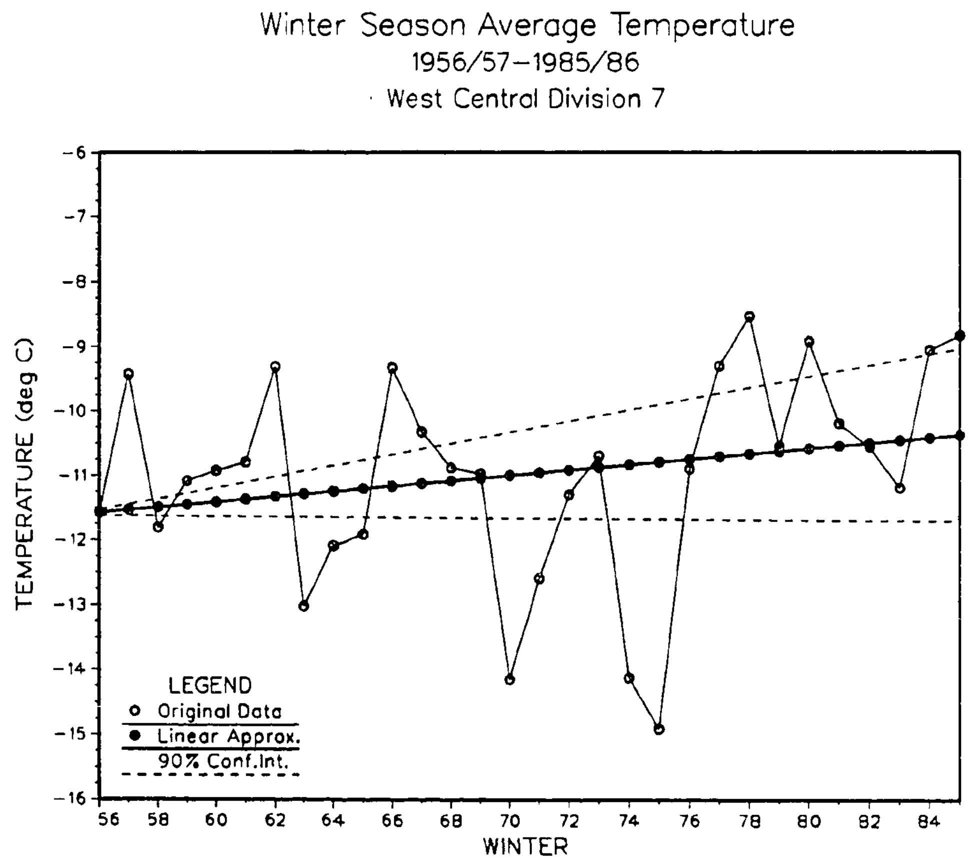


**Figure 4.29** West Central Division 7 Winter Season average temperatures- Winter 1956/57 to 1985/86. winter season data is an average of the six winter months' (October, November, December, January, February, and March) monthly mean data; units are $^{\circ}C$.

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1949), although it appears to have dissipated somewhat in Fairbanks over the latter portion of the study period. The interior's winter temperatures are extremely variable from day to day due to the inland location of the division. Under certain atmospheric conditions such as the influence of the persistent Northern Asia Pattern (Barnston and Livezey, 1987), strong low-level temperature inversions of as much as $20°C$ may occur in the lowest $100m$ of the atmosphere (National Weather Service Forecast Office-Fairbanks, pers. comm.). However, lack of extended sunlight (i.e. a negative radiation balance) reduces the diurnal variation in temperature.

Climate: The climate of the division is sub-arctic and continental. The lack of steady moisture transport into the division and a persistence of low winter temperatures result in precipitation totals substantially less than those in more maritime divisions. Monthly mean precipitation values (Fig. 4.30, Table 4.8b) range from $22mm$ in November to $13mm$ in March. There is little interannual or intermonthly variation in the mean precipitation values. As a result, there are also very few anomalous individual months. November 82 (+), December 84 (+), March 63 (+), and March 67 (+) appear to be the wettest months. There is no significant long-term trend in the seasonal average precipitation data (Fig. 4.31) for the division.

The temperature records (Figs. 4.32 and 4.33, Table 4.8a) of the Interior reflect the truly sub-arctic/ arctic continental nature of the division's climate. They are quite low and quite variable. The largest interannual fluctuations occur in the December, January, and February records. Long-term mean monthly temperatures range from $-5.6°C$ in October to $-22.9°C$ in January. March and November are similar as are December and February. The longest period of below normal temperatures occurred in the January record from 1964- 1976 as in many of the other divisions' records. Two other extended periods of below normal temperatures occurred from 1959- 1964 in March and from 1971- 1976 in February. There are three extended periods of above normal temperatures— 1978- 1982 in November, 1981-1986 in December, and 1978- 1985 in March. The long-term linear trend curve suggests fairly large increases in the mean monthly temperatures of

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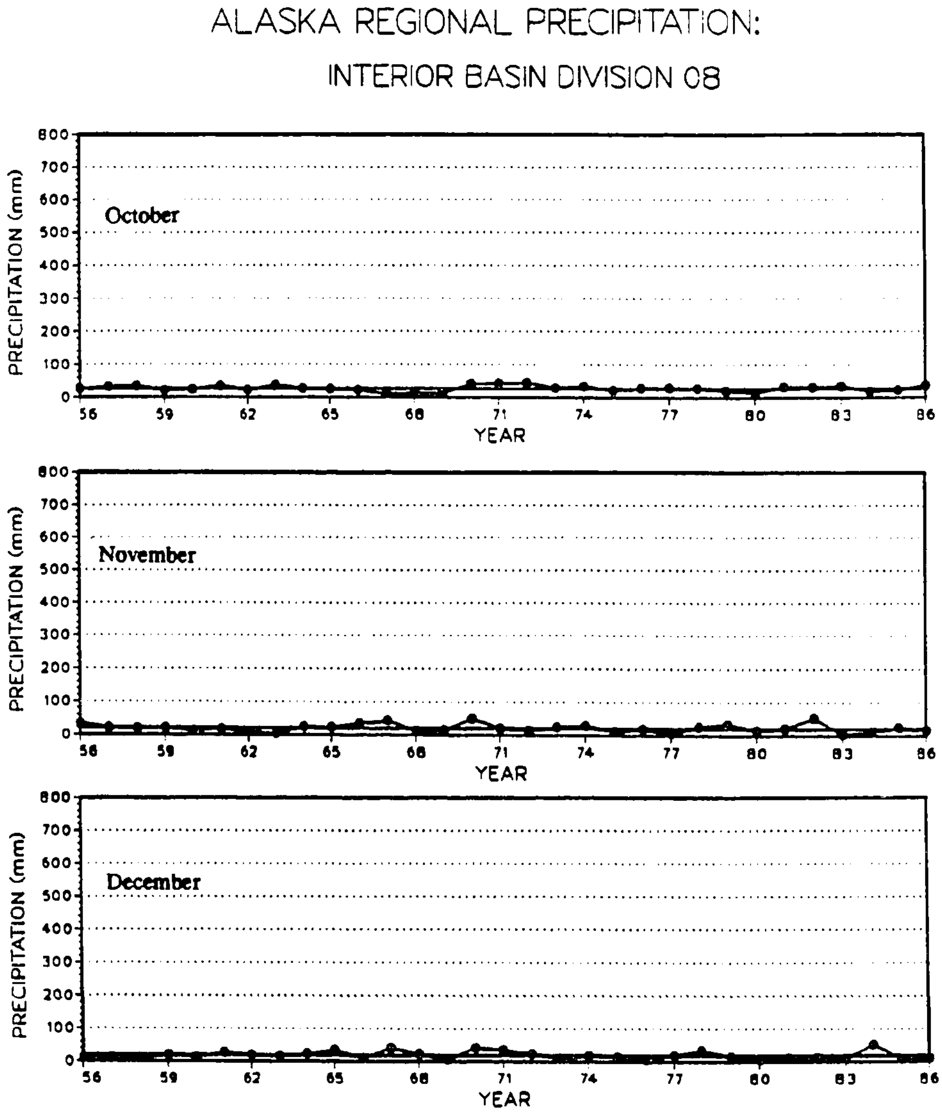


**Figure 4.30** Interior Basin Division 8 monthly mean precipitation- 1956 to 1986 (winter months). year (x-axis) is the actual date of the data, not the winter season date; solid line with points indicated: data, solid line: thirty-year mean data value for month's data depicted, dashed line: trend (linear least squares fit to data); units are *mm*.

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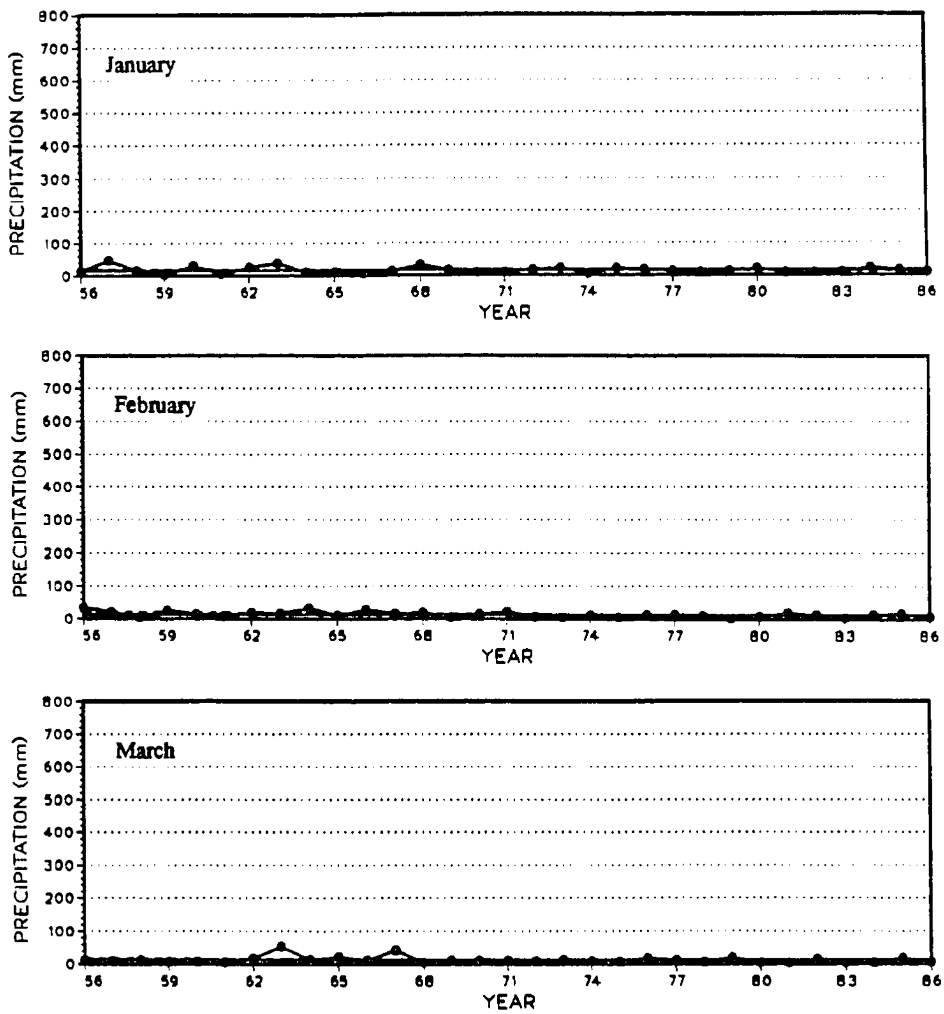


**Figure 4.30cont'd** Interior Basin Division 8 monthly mean precipitation-1956 to 1986 (winter months). units are *mm.*

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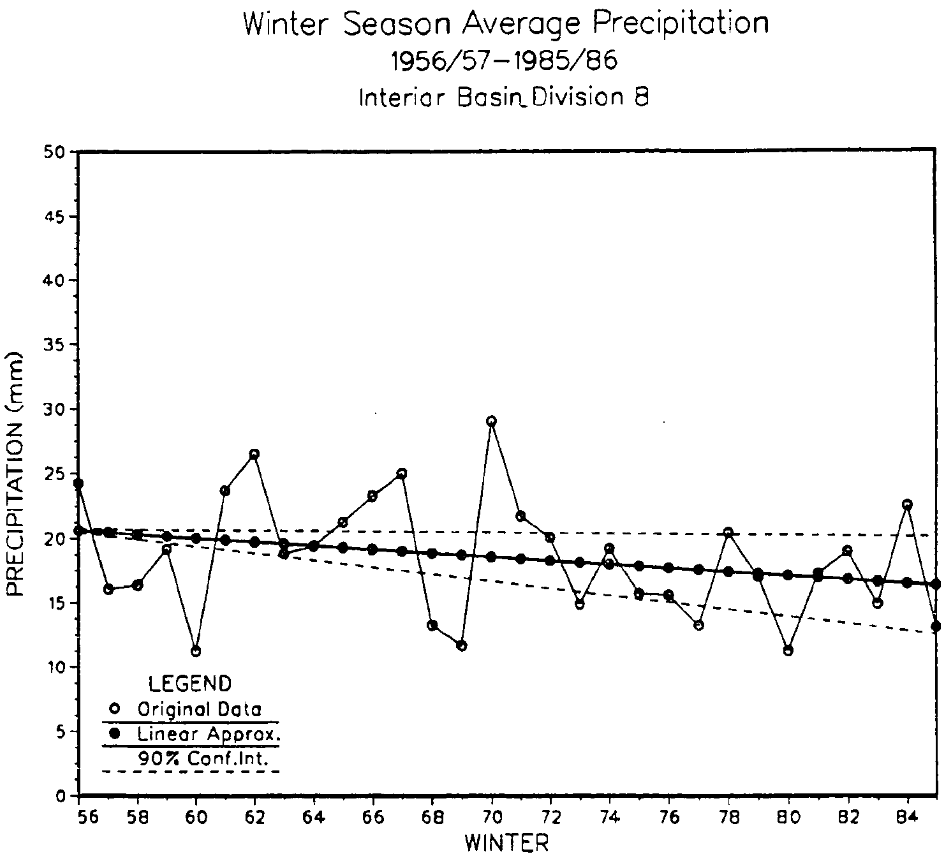


**Figure 4.31** Interior Basin Division 8 Winter Season average precipitation- Winter 1956/57 to 1985/86. winter season data is an average of the six winter months' (October, November, December, January, February, and March) monthly mean data; units are *mm*.

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**Table 4.8a,b** Interior Basin Division 8 monthly mean temperature and precipitation. Winter Season extremes (1956/57 to 1985/86) (a) monthly mean temperature, (b) monthly mean precipitation.

**a**

Monthly Mean Temperature Statistics:
Interior Basin Division
Winter Season 1956-1986

| Month | Max. T | Min. T | Mean T |
|---|---|---|---|
| Oct. | -0.6°$C$ | -10.2°$C$ | -5.6°$C$ |
| Nov. | -7.5 | -23.2 | -16.3 |
| Dec. | -12.7 | -32.1 | -21.9 |
| Jan. | -8.4 | -33.9 | -22.9 |
| Feb. | -12.5 | -30.8 | -19.9 |
| Mar. | -4.3 | -22.0 | -13.4 |

**b**

Monthly Mean Precipitation Statistics:
Interior Basin Division
Winter Season 1956-1986

| Month | Max. P | Min. P | Mean P |
|---|---|---|---|
| Oct. | 44$mm$ | 10 | 20 |
| Nov. | 53 | 4 | 22 |
| Dec. | 52 | 6 | 19 |
| Jan. | 46 | 3 | 16 |
| Feb. | 35 | 2 | 14 |
| Mar. | 54 | 4 | 13 |

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December, January, and February over the thirty year study period. The major individual anomalous months in the Interior Basin temperature records include: March 65 (+), February 79 (-), February 80 (+), January 77 (+), January 71 (-), January 81 (+), January 85 (+), December 80 (-), December 61 (-), December 64 (-), December 85 (+), December 69 (+), November 79 (+), November 75 (-), November 76 (+), and October 69 (+). There is a significant increasing long-term trend in the seasonal average temperature data for the division.

NOAA Observation Sites: Major observation sites within this division are: Bettles, Big Delta, College Observatory, Eielson AFB, McKinley Park, Fairbanks, Northway, Tanana, Tok, Nenana, University Exp. Station, Fort Yukon, Galena, Manley Hot Springs, and McGrath.

### 4.2.9: Division 9: ARCTIC DRAINAGE

Physical Geography: The Arctic Drainage division is the northernmost region in the state. Division boundaries include: the Arctic Ocean to the North, the Brooks Range to the south, Canada's Yukon Territory to the east, and the Bering Strait and Chukchi Seas to the west. The entire division is near to, or north of the Arctic circle and therefore receives minimal sunlight during the winter period. The topography varies from the Brooks Range (elevations: east: $3000m$, west: $900m$) and its foothills to the broad, flat Arctic coastal plain. Several small alpine glaciers such as McCall Glacier (Wendler *et al.*, 1972) are located in the higher elevations of the eastern Brooks Range. The coastal plain is fairly narrow along the Alaska-Canada (ALCAN) boundary, but it widens to several $100km$ along the west/northwest division boundary. In addition, permafrost is continuous along the Arctic coast and extends over 600 meters down from the surface in some locations (Osterkamp, 1987). The Arctic Drainage division is so-called because it serves as a drainage "basin" for major rivers such as the Sagavanirktok, Colville, and Kobuk that drain north and northwest into the Chuckchi Sea and the Arctic Ocean. Throughout the winter season, the ocean along the western and northern shores of this

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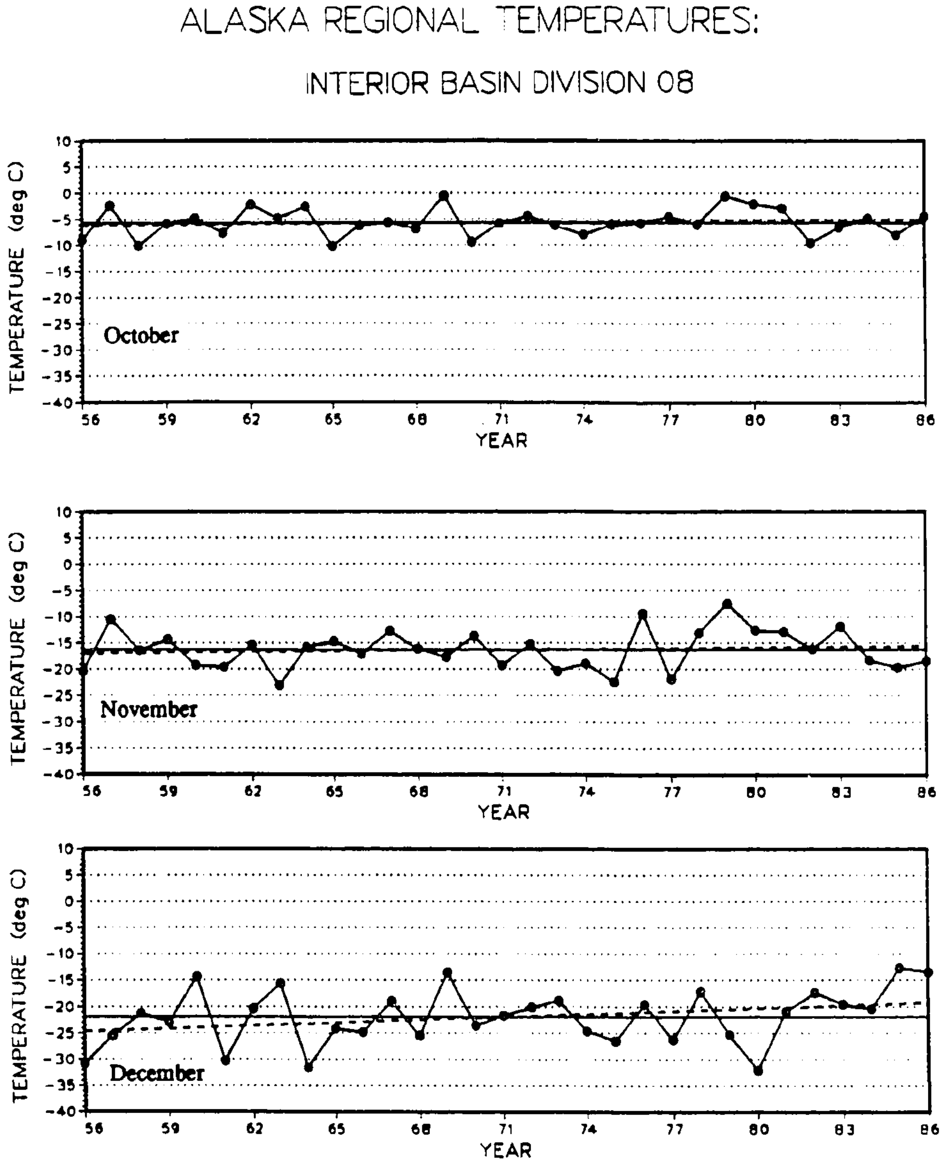


**Figure 4.32** Interior Basin Division 8 monthly average temperatures-1956 to 1986 (winter months). year (x-axis) is the actual date of the data, not the winter season date; solid line with points indicated: data, solid line: thirty-year mean data value for month's data depicted, dashed line: trend (linear least squares fit to data); units are °*C*.

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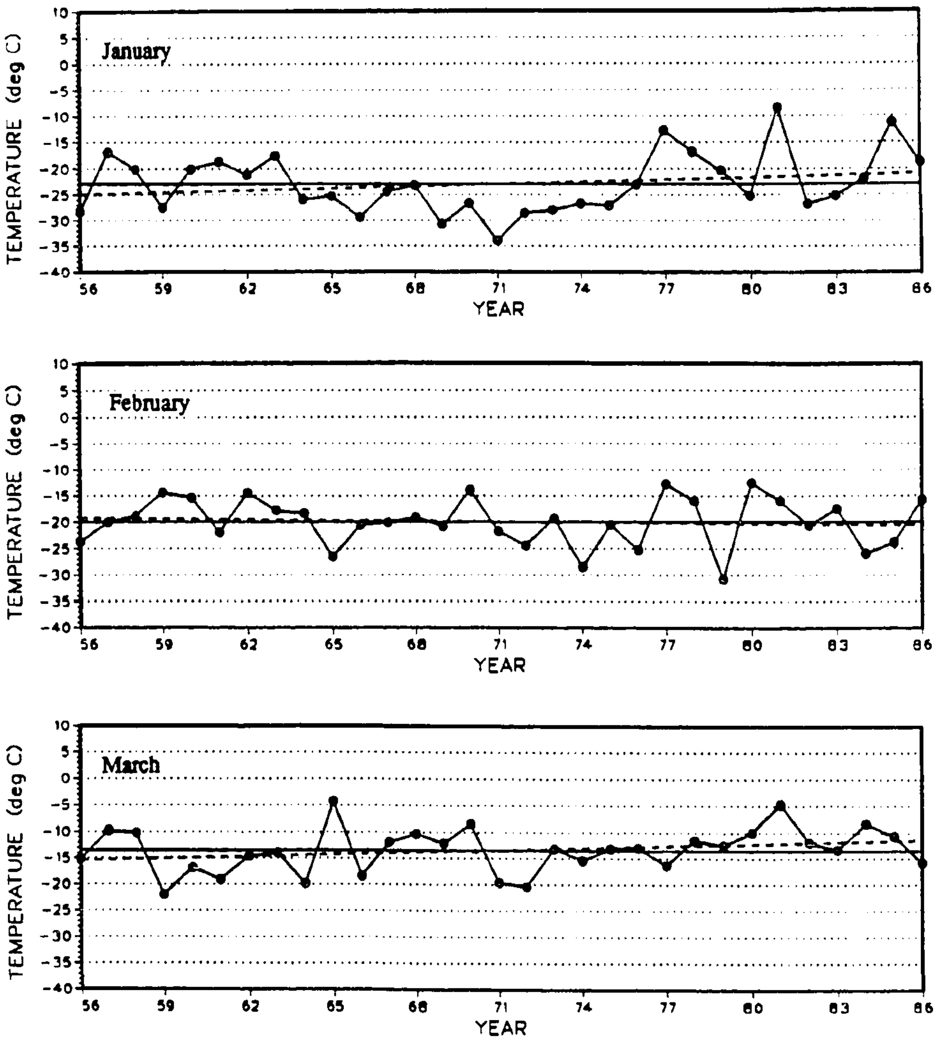


**Figure 4.32cont'd** Interior Basin Division 8 monthly average temperatures-1956 to 1986 (winter months). units are $^{\circ}C$.

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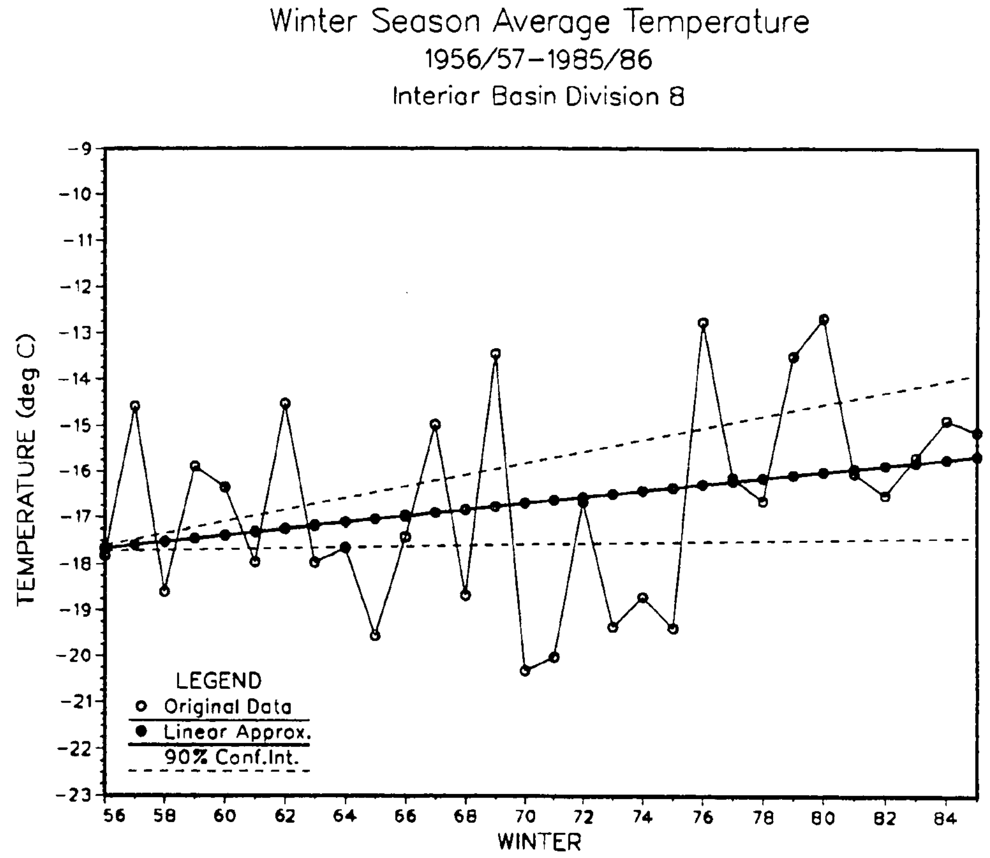


**Figure 4.33** Interior Basin Division 8 Winter Season average temperatures- Winter 1956/57 to 1985/86. winter season data is an average of the six winter months' (October, November, December, January, February, and March) monthly mean data; units are °$C$.

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division is covered with seasonal and multi-year sea ice (Untersteiner, 1986). Although the winter snowfall is light in comparison with the southern divisions of the state. Stiff, almost constant winds blow east/northeast or west off the frozen ocean creating large drifts of snow against the lee-side of any elevated terrain.

Climate: The Arctic Drainage has the harshest winter climate of all the Alaskan divisions.

The presence of highly unfavorable conditions (low temperatures, frozen ocean) for precipitation has resulted in low totals throughout this division. Long-term monthly mean values (Fig. 4.34, Table 4.9b) range from a high of $20mm$ in October to a low of $6mm$ in February. December, January, February, and March all have monthly mean values less than or equal to $10mm$. October is the most variable month in terms of interannual variability. This could be a reflection of the year to year fluctuation in near-shore sea ice development. In years when the ice forms late, October precipitation may be heavier due to the presence of the open water source. There are no long-term trends of increase or decrease evident in the time series'. Individual anomalous periods are also scarce. Only January of 1962 and 1963 are notably above normal. There is no significant long-term trend in the seasonal average precipitation data (Fig. 4.35) for the division.

As a result of the minimal incoming solar radiation, air temperatures are extremely low. The long-term time series of monthly mean temperatures (Fig. 4.36, Table 4.9a) shows values ranging from $-8.5°C$ in October to $-25.6°C$ in February. December, January, February, and March all have long-term monthly mean temperatures below the $-20°C$ mark. The coldest individual monthly mean temperature, $-35.2°C$, occurred in February of 1984. The warmest monthly mean temperature was $-3.7°C$ for October 1969. Interannual variability is large in all six winter months, but most pronounced in December, January, and February. The longest extended period of below normal temperatures was the period from 1969- 1976 in January. The longest period of above normal temperatures occurred from 1978-1985 in March. Between 1966 and 1983, the February mean temperatures appear to have fluctuated between above normal and below normal temperatures every

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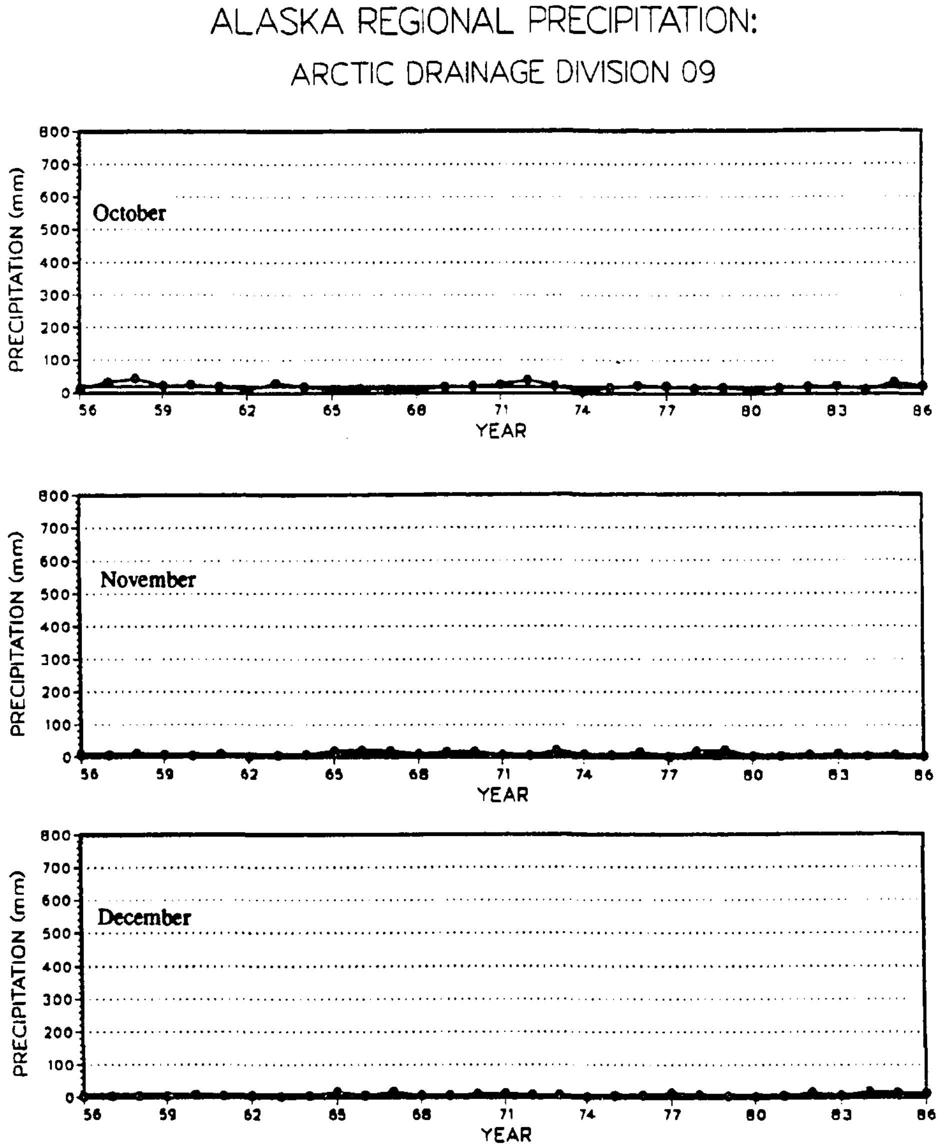


**Figure 4.34** Arctic Drainage Division 9 monthly mean precipitation- 1956 to 1986 (winter months). year (x-axis) is the actual date of the data, not the winter season date; solid line with points indicated: data, solid line: thirty-year mean data value for month's data depicted, dashed line: trend (linear least squares fit to data); units are *mm*.

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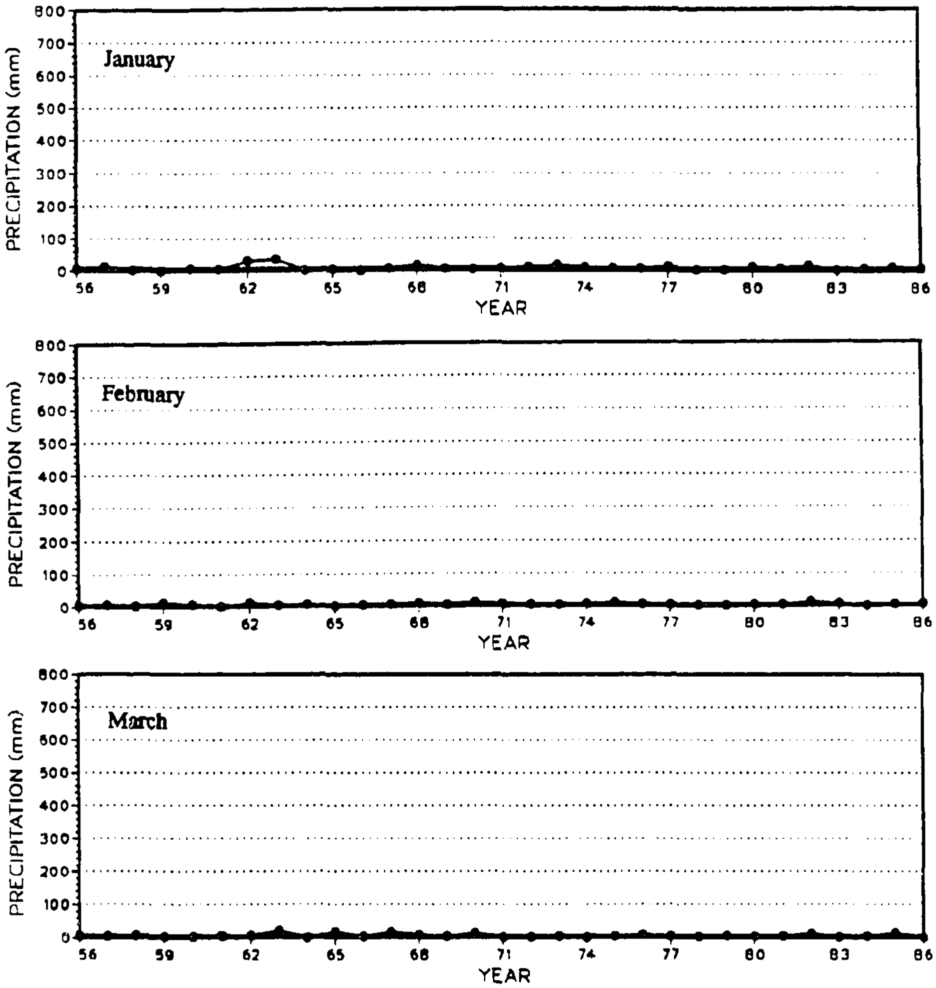


**Figure 4.34cont'd** Arctic Drainage Division 9 monthly mean precipitation-1956 to 1986 (winter months), units are *mm*.

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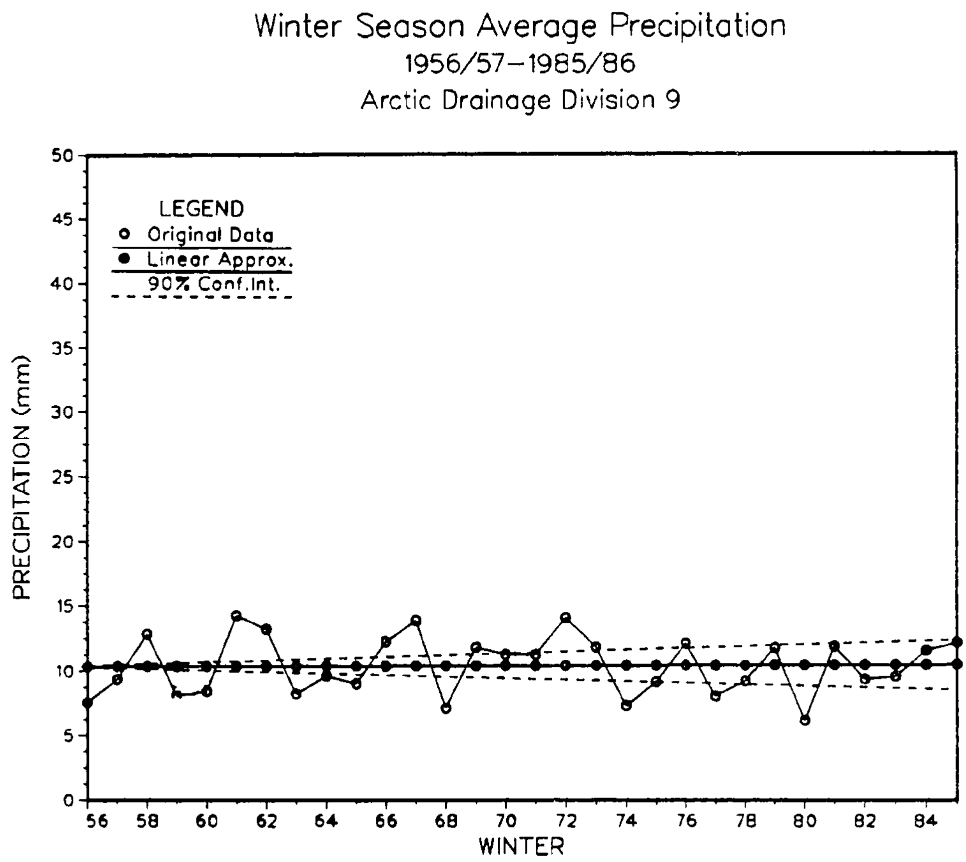


**Figure 4.35** Arctic Drainage Division 9 Winter Season average precipitation- Winter 1956/57 to 1985/86. winter season data is an average of the six winter months' (October, November, December, January, February, and March) monthly mean data; units are *mm.*

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**Table 4.9a,b** Arctic Drainage Division 9 monthly mean temperature and precipitation statistics. Winter Season extremes (1956/57 to 1985/86) (a) monthly mean temperature, (b) monthly mean precipitation.

**a**

Monthly Mean Temperature Statistics:
Arctic Drainage Division
Winter Season 1956-1986

| Month | Max. T | Min. T | Mean T |
|---|---|---|---|
| Oct. | -3.7°$C$ | -14.7°$C$ | -8.5°$C$ |
| Nov. | -10.9 | -22.6 | -16.9 |
| Dec. | -14.5 | -30.7 | -22.4 |
| Jan. | -15.6 | -28.2 | -22.8 |
| Feb. | -18.2 | -35.2 | -25.6 |
| Mar. | -17.0 | -30.4 | -23.3 |

**b**

Monthly Mean Precipitation Statistics:
Arctic Drainage Division
Winter Season 1956-1986

| Month | Max. P | Min. P | Mean P |
|---|---|---|---|
| Oct. | 43$mm$ | 4 | 20 |
| Nov. | 24 | 2 | 11 |
| Dec. | 19 | 2 | 9 |
| Jan. | 36 | 1 | 10 |
| Feb. | 14 | 1 | 6 |
| Mar. | 21 | 0 | 7 |

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other year. There are no apparent long- term trends of temperature increase or decrease in this division's record. The most prominent anomalous months are : March 75 (+), March 77 (-), February 62 (+), February 84 (-), December 58 (+), December 74 (-), December 59 (-), and October 70 (-). There is no significant long-term trend in the seasonal average temperature data (Fig. 4.37) for the division.

NOAA Observation Sites: Major observation sites within this division include Kotzebue, Ambler, Barrow, Barter Island, and Cape Lisburne.

### 4.2.10: Division 10: GULF OF ALASKA

Physical Geography:

The Gulf of Alaska can be described as follows:

> It forms a semi-circular bight opening southward into the North Pacific Ocean. Bathymetrically, it is characterized by a broad ($75 - 150km$) and deep ($150 - 250m$) continental shelf having numerous ridge and trough features. The most prominent of these features are Middleton Island, located near the shelf break in the central gulf, Kayak Island to the northeast of Middleton Island and a trough that extends from the deep ocean, bifurcating into branches which extend toward Yakutat Bay and Hinchinbrook Entrance. In the western gulf, the most significant feature is Kodiak Island. Seaward of the shelf, depths increase rapidly to $4 - 5km$. The shoreline, itself, is characterized by intricate bays, coves, inlets, and fjords (Royer and Muench, 1978).

The water masses of the gulf are an extension of the North Pacific Ocean. The major current feature is a branch of the North Pacific Current. This current consists of water masses that are formed by the mixing of Kuroshio and Oyashio water (Sverdrup *et al.*, 1949). The current splits into two branches as it approaches North America. One branch turns north into the Gulf of Alaska and the other flows south to the continental U.S. The first of these branches forms part of the counterclockwise gyre that makes up the the primary circulation in the Gulf of Alaska (Royer and Emery, 1987). Because it enters the gulf region from the south, this water mass has warm current characteristics, in addition to its subarctic water composition (Sverdrup *et al.*, 1949). Wintertime salinities range from $30ppt$ to $32ppt$ (Xiong and Royer, 1987). Along with the large scale gyre

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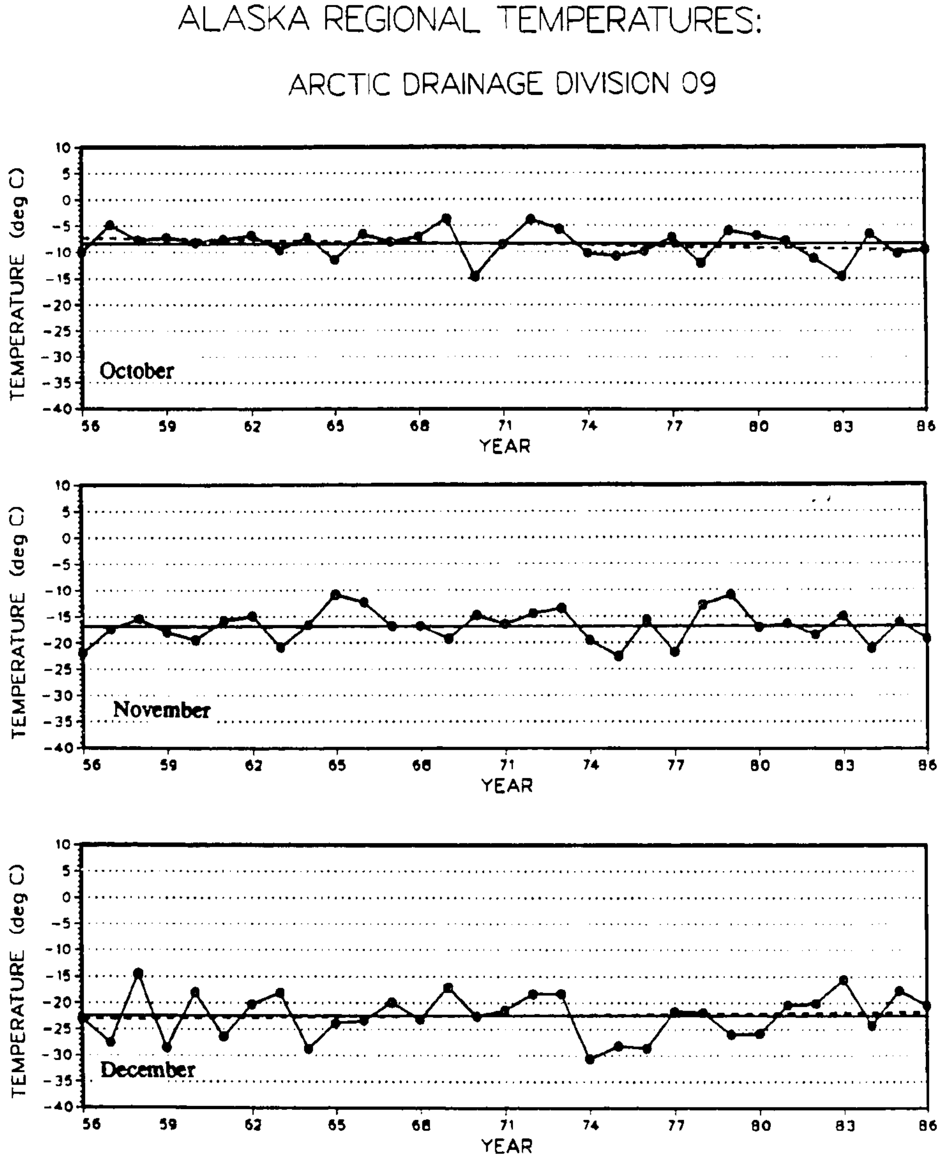


**Figure 4.36** Arctic Drainage Division 9 monthly average temperatures-1956 to 1986 (winter months). year (x-axis) is the actual date of the data, not the winter season date; solid line with points indicated: data, solid line: thirty-year mean data value for month's data depicted, dashed line: trend (linear least squares fit to data); units are $^{\circ}C$.

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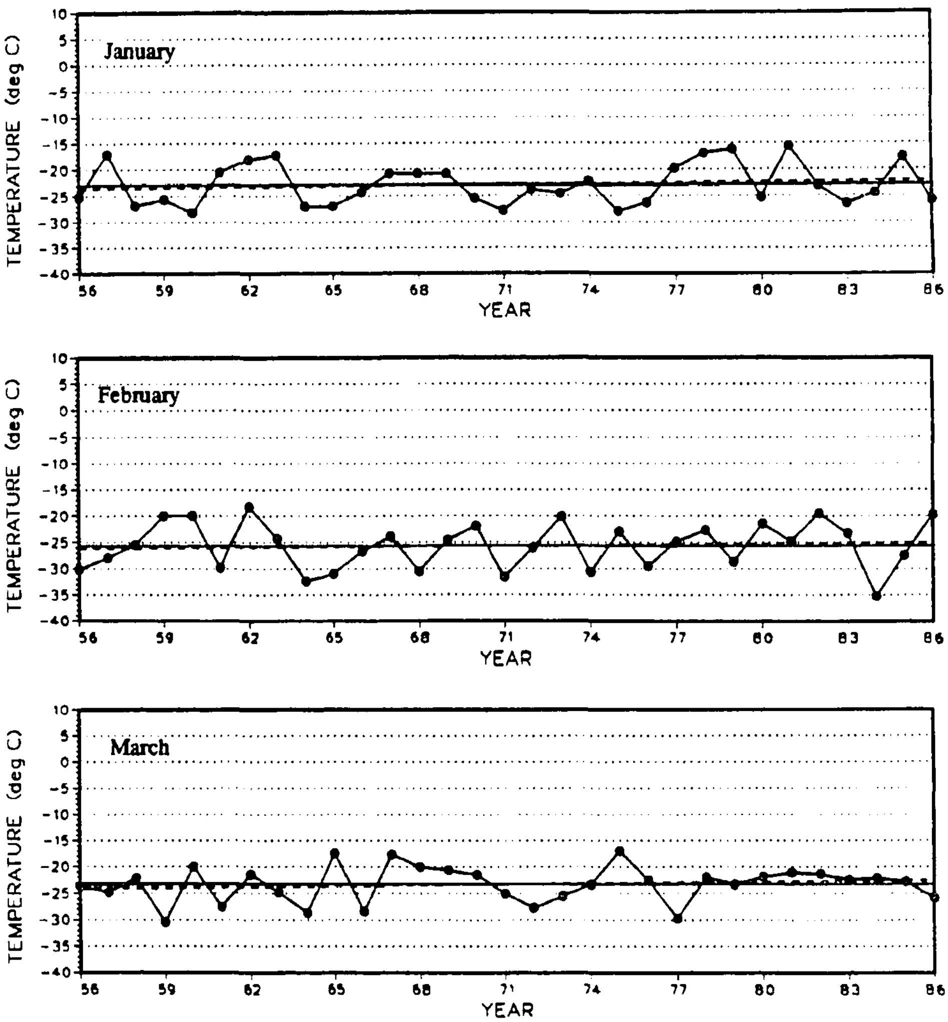


**Figure 4.36cont'd** Arctic Drainage Division 9 monthly average temperatures-1956 to 1986 (winter months). units are °$C$.

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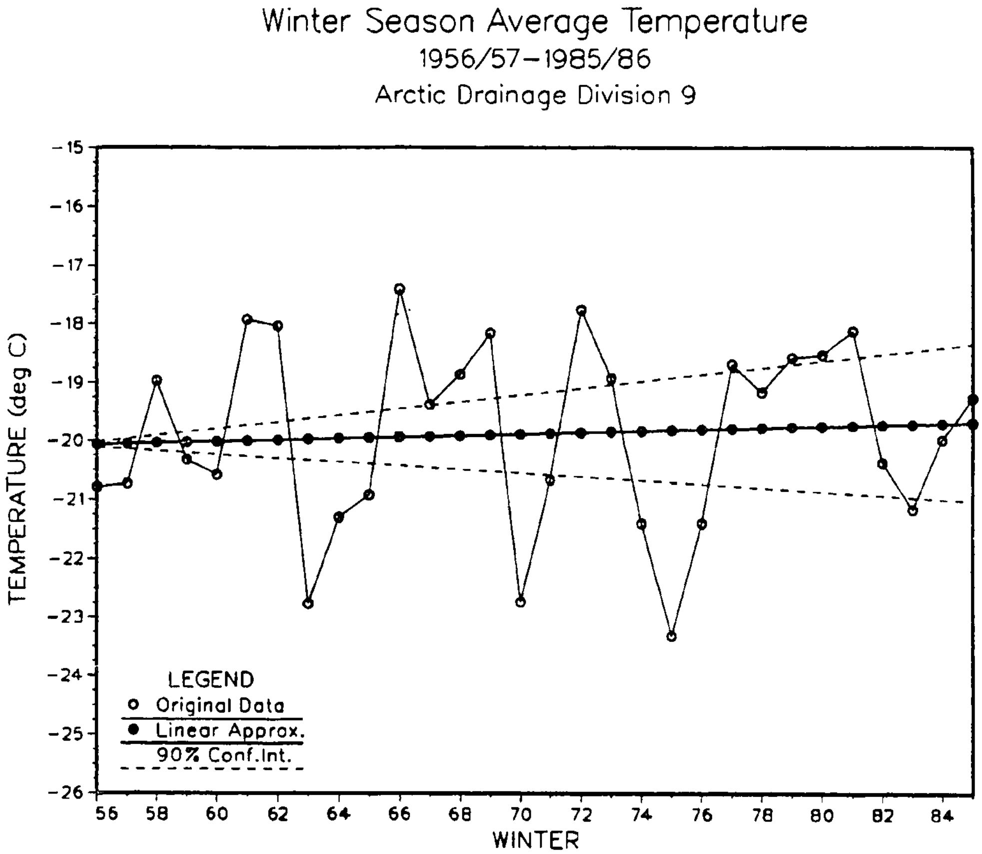


**Figure 4.37** Arctic Drainage Division 9 Winter Season average temperatures- Winter 1956/57 to 1985/86. winter season data is an average of the six winter months' (October, November, December, January, February, and March) monthly mean data; units are $°C$.

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feature, there is evidence of several smaller scale circulation features. One of these is the "currents flowing east and south along the north and east coasts of the gulf with weak anticyclonic circulation" (Royer and Muench, 1978). The northward flowing Alaska current appears to be displaced west when this circulation develops (Royer and Muench, 1978; Royer and Emery, 1987).

Another smaller scale feature apparent is a narrow band of nearly fresh water near the shelf break between the coast and deep water. This coastal current, the Alaska Coastal Current, is driven by a combination of freshwater discharge from the many small streams draining the coastal mountains, and wind stress (Royer, 1981). The core of the current has velocities greater than $66ms^-1$ at its peak (Royer, 1982). The jet is considered to be both geostrophic and baroclinic (Royer, 1981). Mean transport by the current is about $0.24 \times 10^6 m^3 s^- 1$ (Royer, 1981). It is thought that 40% of the freshwater that enters the Northeast Pacific from the atmosphere is transported by this current (Royer, 1982). The current extends from Southeastern Alaska and British Columbia along the coast to the western Gulf of Alaska. The current is distinct from the Alaska Current except in the vicinity of Kayak Island (Royer and Muench, 1978; Royer, 1981).

Sea ice is not prominent in the gulf. The sea ice that does form is found in the many intricate bays, inlets and fjords marking the shoreline. Example locations include Cook Inlet, the south shore of the Alaskan Peninsula, and the Shelikof Straits (Browner *et al.*, 1977). The sea ice in these regions is quite variable both in terms of thickness and in terms of existence. It is rarely present outside of Cook Inlet. Other ice present along the coast is most likely to be freshwater ice in the form of icebergs from glaciers.

Climate: The winter climate of the division is stormy. The western Gulf and Aleutians form a major birthplace of the Aleutian Low atmospheric feature (Mo and Ghil, 1987) and the vigorous storms spawned by the dynamic interactions of water masses and atmosphere (Namias, 1975; Anderson *et al.*, 1988; Xiong and Royer, 1987). These storms propagate eastward with intense winds resulting in coastal downwelling. Although the mean winter wind is easterly, there are also

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strong continental drainage winds that blow seaward down through the coastal ranges creating low air temperatures and thus further enhancing the winter atmosphere-sea thermal contrast.

Long-term monthly mean SST (Fig. 4.38, Table 4.10) values range from $13.3°C$ in October to $6.2°C$ in March. The winter sea surface temperatures appear to lag the land-based winter temperatures. With the exception of the Arctic Drainage Division, all of the land-based divisions show signs of seasonal warming by February. Extended periods of below average monthly mean SST values occurred from 1966-1977 (except 1974) in October, November 1962-1978, January 1962-1979, February 1964-1978, and March 1964-1976. The period from 1956 to the early 1960's was characterized by above normal temperatures in all six winter months. The period after 1978 was, in general, average or slightly above normal. Data compiled by Royer (1989) suggests that there has been an increase in temperature of $1.5°C$ since 1970. There appears to be no consistent long-term change indicated over the thirty year period from 1956-1986. The only indication of any long-term change is a cooling in October, November, and December. However, there is a strong suggestion of a very low frequency (VLF) oscillation in sea surface temperatures. The period appears to be in the range of 25 years. Royer (1989) has proposed that this VLF phenomenon has a period of 28 years and is limited to high latitudes. The thirty-year winter season average SST data shown in Fig. 4.39 shows a similar oscillation.

On a somewhat shorter time scale, Gulf SST response to the known ENSO or El Nino-Southern Oscillation episodes (Namias and Cayan, 1981; Namias *et al.*, 1988; Niebauer, 1988; Rodgers, 1976; Walsh and Richman, 1981; Namias, 1976; Namias, 1978; Namias, 1969; Douglas *et al.*, 1982; Davis, 1976; Clark, 1972; Xiong and Royer, 1987) appears to be mixed. The Gulf of Alaska SST's increased in all six winter months during the ENSO events of 1957/58 and 1969/70. The temperatures increased slightly during the first half of the winter season concurrently with the ENSO events of 1965/66 and 1972/73. The ocean response to the 1972/73 ENSO event may have been limited by the fact that the ENSO activity did not seem to propagate to the high latitudes (Enfield and Allen,

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1983; Cane, 1983). The temperatures increased slightly in all but one month of the season during the ENSO's of 1963/64 and 1976/78. Finally, there was very little warming, if any, concurrent with the 1982/83 ENSO. However, a notable warming is evident in the time series for the season following the 1982/83 ENSO. Although, warming of Gulf SST temperatures was evident during almost all of the ENSO episodes, there were also other equally-strong warming/cooling periods occuring in non-ENSO seasons.

Individual anomalous months include: November 57 (+), October 76 (-), January 57 (+), January 85 (+), November 71 (-), January 85 (+), and March 69 (-). There is no significant long-term trend indicated by a *linear* fit to the seasonal average sea surface temperature data.

SIO Data Observation Sites: The raw data are five degree gridded monthly mean sea surface temperature data for the Gulf of Alaska from the Scripps Institution of Oceanography (J. Namias, Scripps Institution of Oceanography, La Jolla, CA). The gridpoint breakdown is as follows:

$45°N$ : 5° intervals from $170°W$ to $130°W$;
$50°N$ : 5° intervals from $170°W$ to $130°W$;
$55°N$ : 5° intervals from $170°W$ to $135°W$;
$60°N$ : $145°W$.

Gridpoint data have been averaged to obtain a monthly mean SST time series for the entire Gulf of Alaska region.

### 4.3: Summary

From the data presented in this chapter, it is indeed evident that the winter season climate of Alaska is quite variable from year to year, from month to month, and from one geographic division to another. The heaviest precipitation occurs along the north and east boundaries of the Gulf of Alaska. This is also the location of the most extreme interannual fluctuations in precipitation amounts. The greatest interannual temperature variability is seen in the West Central and Interior Basin Divisions.

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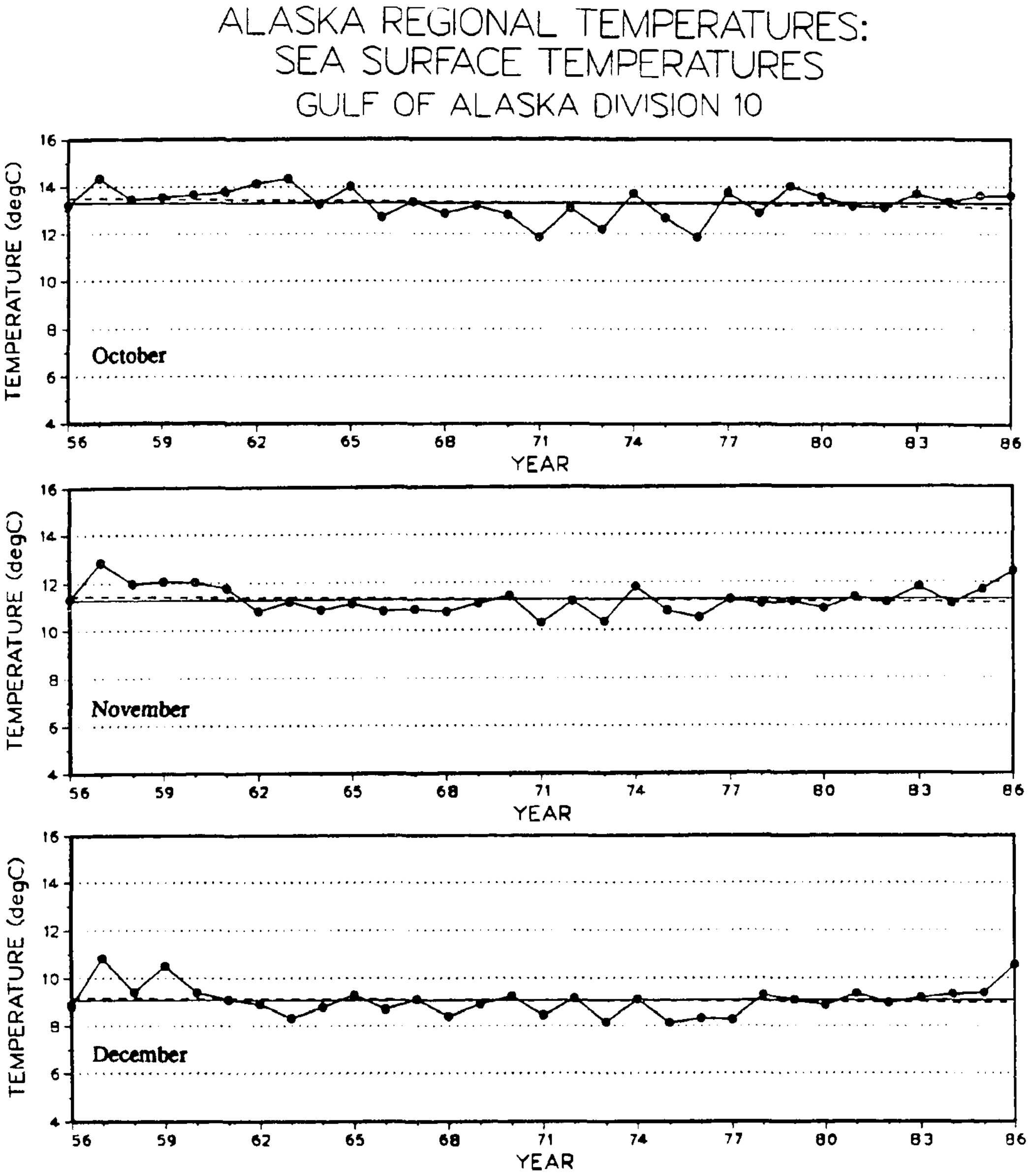


**Figure 4.38** Gulf of Alaska Division 10 monthly average sea surface temperatures-1956 to 1986 (winter months). year (x-axis) is the actual date of the data, not the winter season date; solid line with points indicated: data, solid line: thirty-year mean data value for month's data depicted, dashed line: trend (linear least squares fit to data); units are °$C$.

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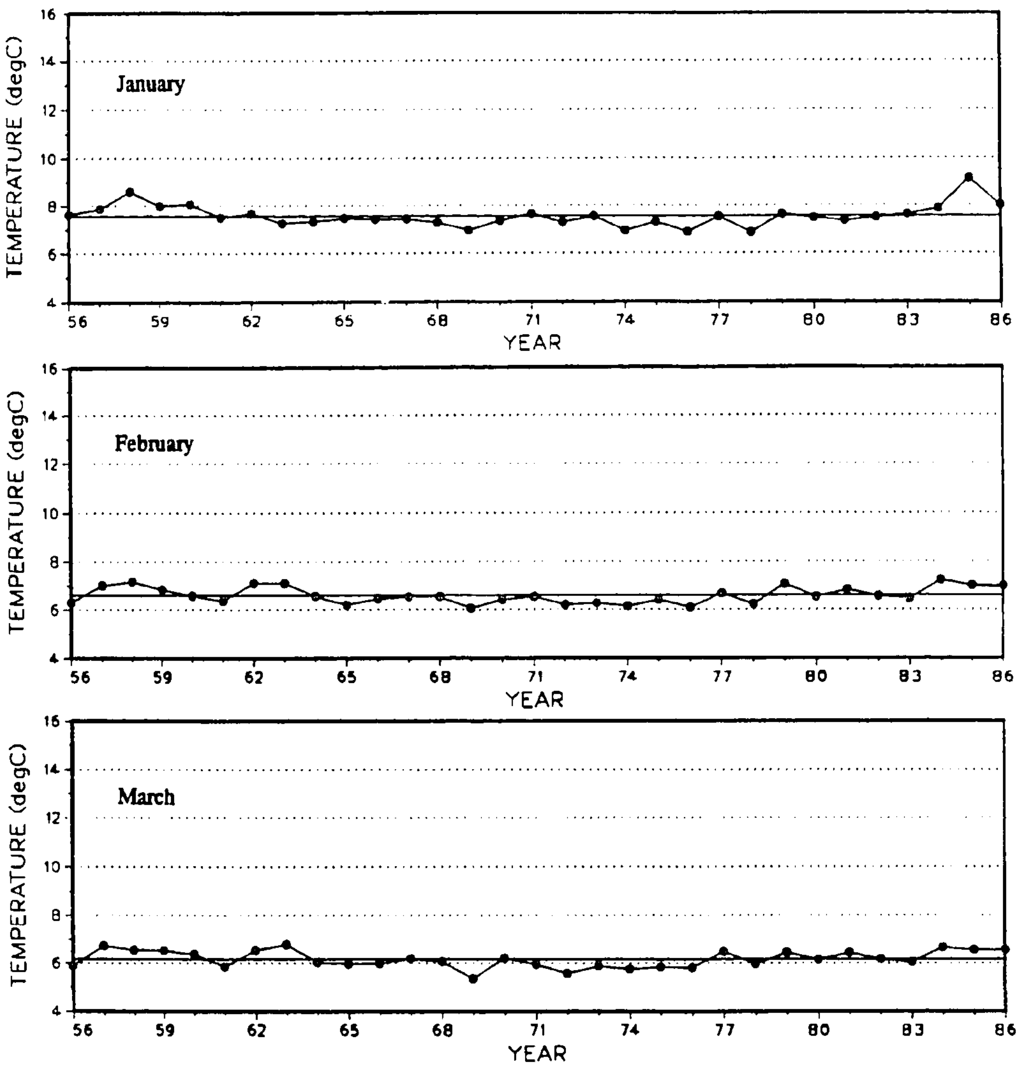


**Figure 4.38cont'd** Gulf of Alaska Division 10 monthly average sea surface temperatures-1956 to 1986 (winter months). units are $^\circ C$.

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**Table 4.10** Gulf of Alaska Division 10 monthly mean SST statistics. Winter Season extremes (1956/57 to 1985/86).

| Monthly Mean Sea Surface Temperature Statistics: Gulf of Alaska Division Winter Season 1956-1986 | | | |
|---|---|---|---|
| Month | Max. T | Min. T | Mean T |
| Oct. | 14.3°$C$ | 11.8°$C$ | 13.3°$C$ |
| Nov. | 12.8 | 10.3 | 11.3 |
| Dec. | 10.8 | 8.1 | 9.1 |
| Jan. | 9.1 | 6.9 | 7.6 |
| Feb. | 7.2 | 6.1 | 6.6 |
| Mar. | 6.8 | 5.3 | 6.2 |

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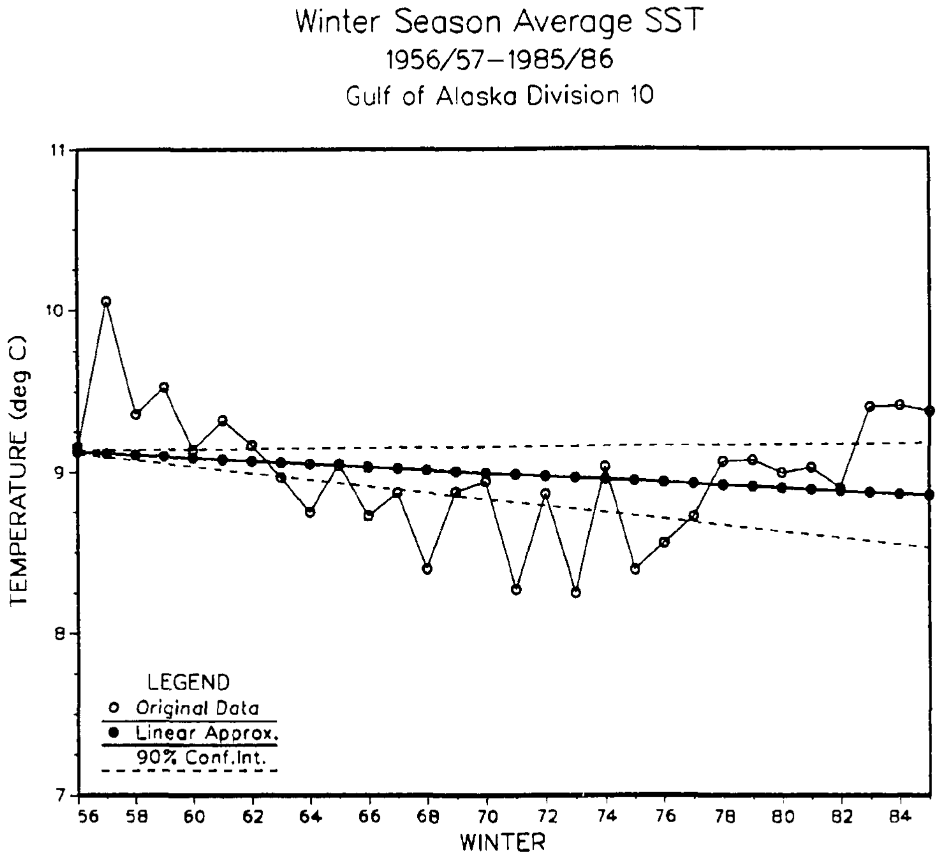


**Figure 4.39** Gulf of Alaska Division 10 Winter Season average sea surface temperatures-Winter 1956/57 to 1985/86. winter season data is an average of the six winter months' (October, November, December, January, February, and March) monthly mean data; units are $°C$.

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Records indicate that when the Gulf of Alaska sea surface temperatures are lower than normal, the land-based divisions are also cooler than normal. This was especially true during the time period from 1964-1977. There is evidence of long-term warming in the mid-winter (December, January, and February) temperatures in the Cook Inlet, Bristol Bay, West Central and Interior Basin Divisions. Copper River temperatures appear to be decreasing during these months. Precipitation records show a positive trend during January in the Southeastern Division, and during December and January in the South Coast Division. A decrease in precipitation is suggested for November and December in the Southeastern Division. Overall, the statewide records indicate that the winter months of the late 1950's and early 1960's were warmer than their respective thirty-year mean values. This was a period of above average (thirty-year mean) monthly mean precipitation for the first three months and below normal values for the latter three months of each winter season. The period between 1964-1977 was cold and dry throughout the winter seasons. This cold, dry episode was most pronounced in the January time series. After 1977, both temperature and precipitation become extremely variable within the season, from one geographical division to another, and from winter to winter.

Winter season average temperature and precipitation data show characteristics similar to the individual monthly-mean time series. The coldest seasons throughout the state occurred between 1968 and 1975. The period following the cold was quite variable. This variable period was also warmer than the period preceding the cold winter season period. *Linear* approximations to the data indicated a significant (90% C.I.) warming trend in the Bristol Bay Division and in the Interior Basin Division. Other trends may exist elsewhere in the state, but due, in part, to the relatively cyclic tendencies in the temperature behavior, they were not evident from the linear fit.

Long-term time series plots of winter season average precipitation values reveal the large variability in precipitation on an interannual and interdivisional basis. A *linear* approximation to the data indicates a significant (90% C.I.) decrease in the Copper River Division precipitation and a

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significant (90% C.I.) increase in the Southwestern Islands Division precipitation over the period from 1956-1986.

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## Chapter 5: Synoptic Climatology

In the previous chapters, the atmospheric circulation and the surface climate of Alaska were examined as separate entities. In this chapter, the final step of combining the two components into a synoptic climatology describing the region's winter climate is taken. As stated at the beginning of this thesis, a synoptic climatology is a means of "obtaining insight into local or regional climates by examining the relationship of weather elements, individually, or collectively to atmospheric circulation processes" (Barry and Perry, 1973).

### 5.1 Correlation Process

The correspondence between surface climate and $700mb$ anomaly circulation is examined in three formats— statewide (geographic/spatial), climate division (geographic/spatial), and specific climate event (case study application of the first two). In the first two cases, circulation patterns are defined in terms of the division climate that occurs when the patterns are present. For instance, if a climate division experiences below normal temperatures four out of five times that Basic Anomaly Pattern 4 (BP4) occurs, the pattern is designated cold for that division. For the purpose of this investigation, normal is defined to be equal to the long-term (thirty-year) mean for the specific month and climate division in question. If a division's temperatures are equally warm and cold during the pattern's existence over the thirty-year study period, that pattern becomes a mixed (denoted as w/c) climate pattern. Precipitation associations are determined in the same manner. Statewide climate characteristics are determined by averaging the individual nine land-based divisions' (Fig 5.1) climate characteristics. The statewide climate is then treated as a large-scale division for purposes of determining associations between circulation and climate. The third form of examining possible



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associations involves the application of results from the statewide and regional investigations to selected individual climate events.

### 5.2 Large-scale Synoptic Climatology

Before proceeding to division climate/ anomaly pattern associations, the statewide or large-scale associations were examined. This provided a means of examining the long-term variability in the large-scale climate. It also provided a general reference for the smaller-scale relationships. The results depicted in Table 5.1 indicate that Basic Anomaly Pattern 2 (BP2), BP3, BP5, and BP8 are associated with warmer than normal temperatures. BP1, BP4, BP6, BP7, and BP10 exist primarily during colder than normal episodes. BP9 has a mixture of warm and cool episodes associated with it over the thirty years. BP6 and BP10 are wetter than normal. BP1, BP3, BP4, BP8, and BP9 are generally present during dry episodes. Finally, BP2, BP5, and BP7 are associated with a mixed precipitation climate.

The most notable "large-scale" episode in the Alaska winter climate record was the colder than normal period of January temperatures. This cold episode lasted from 1964-1976. It was apparent in all 10 of the climate division temperature records, but it was most pronounced in the more interior divisions. Precipitation values were also well below normal throughout the state. During this cold, dry period, BP3 (Figs. 3.11a and 3.16a) and BP8 (Figs. 3.13b and 3.18b) were seen quite infrequently. These are both warm patterns on the statewide scale. Both patterns existed prior to and after the cold period. BP1 (Figs. 3.10a and 3.15a), a cold pattern, was frequently present during the cold period. This time was also a cold period for the Gulf of Alaska sea surface temperatures and the entire North Pacific SST's (Namias and Cayan, 1988, Royer, 1989). These results indicate that a connection exists between monthly-mean $700mb$ atmospheric fluctuations, SST's in the North Pacific, and surface climate variability. This specific relationship is further supported by Hamack

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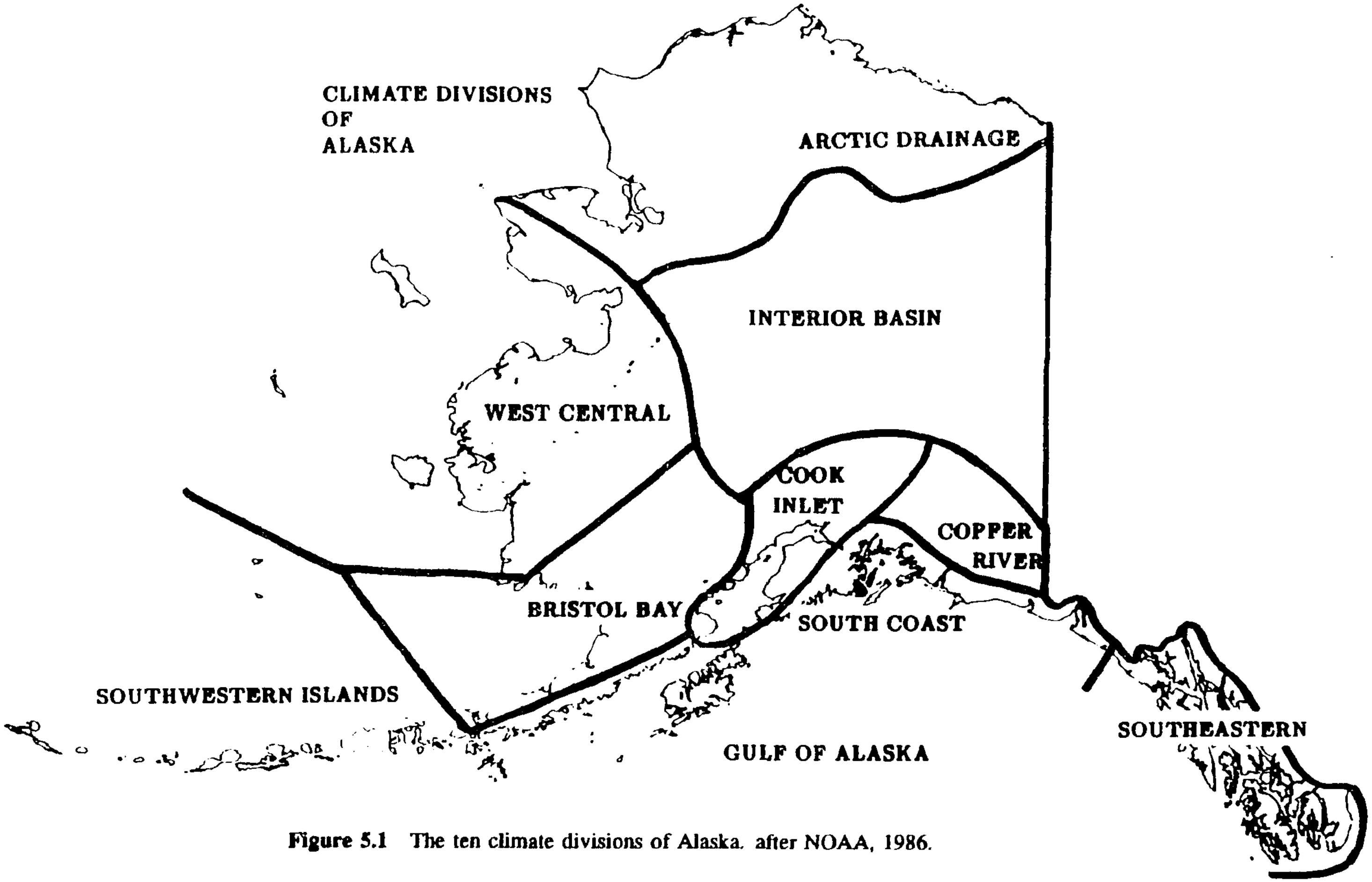


**Figure 5.1** The ten climate divisions of Alaska, after NOAA, 1986.

**Table 5.1** Statewide monthly mean climate and Basic Anomaly Pattern associations–Winter Season 1956/57 to 1985/86. relationship between the ten Basic Anomaly Patterns and the statewide surface-level monthly mean temperature and precipitation characteristics; w/c=mixed temperature, w/d=mixed precipitation (see text for further explanation).

| Statewide Correlation Results: Alaska Month Anomaly Patterns | | |
|---|---|---|
| Pattern | Temperature | Precipitation |
| 1 | cool | dry |
| 2 | warm | w/d |
| 3 | warm | dry |
| 4 | cool | dry |
| 5 | warm | w/d |
| 6 | cool | wet |
| 7 | cool | w/d |
| 8 | warm | dry |
| 9 | w/c | dry |
| 10 | cool | wet |

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and Broccoli (1979) who used a thermal wind approach to show that cold North Pacific sea surface temperatures were associated with enhanced $700mb$ westerly or northwesterly flow.

### 5.3 Division Synoptic Climatology

Once the statewide/large-scale associations were established, attention was focused on the ten individual climate divisions defined in Chapter 4. The relationships between each Basic Anomaly Pattern and each regional climate division are shown in Tables 5.2a,b to 5.6a,b. The method of defining a pattern as warm, cold, or mixed is the same as that used in the large-scale investigation. For example, if the climate in a specific division was warmer than normal during 4 out of 5 occurrences of Basic Anomaly Pattern 3 (BP3), then, BP3 is designated as a warm pattern for that climate division. Precipitation is handled similarly.

In the Southeastern Division (Table 5.2a), warm patterns are generally wet. They are characterized by below normal heights over the Gulf of Alaska and south/southwesterly flow. Cool patterns are composed of above normal heights over the western Gulf of Alaska and northerly flow.

Cool South Coast Division (Table 5.2b) patterns tend to be dry. Prominent features include above normal heights over the Aleutians and north/northeasterly flow. Warm patterns are wet. Southwesterly or southerly flow is characteristic of the warm patterns.

All ten Basic Anomaly Patterns show mixed or warm climate associations in the Southwestern Islands Division (Table 5.3a). They are also dry or mixed in terms of precipitation.

Warm Copper River Division (Table 5.3b) patterns are wet patterns and cool patterns are dry. Negative height departures over the western Gulf of Alaska and southerly/ southeasterly flow are dominant warm pattern characteristics. Cool patterns have above normal heights positioned over the Aleutians.

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**Table 5.2a,b** Monthly mean climate and Basic Anomaly Pattern associations–Southeastern Division 1 and South Coast Division 2. Winter Season (1956/57 to 1985/86) relationships between the ten Basic Anomaly Patterns and (a) Southeastern Division 1, (b) South Coast Division 2 monthly mean temperature and precipitation characteristics; w/c=mixed temperature, w/d=mixed precipitation (see text for further explanation).

| a | Regional Correlation Results: Southeastern Month Anomaly Patterns | |
|---|---|---|
| Pattern | Temperature | Precipitation |
| 1 | cool | dry |
| 2 | warm | wet |
| 3 | warm | wet |
| 4 | cool | dry |
| 5 | warm | dry |
| 6 | warm | wet |
| 7 | cool | dry |
| 8 | cool | dry |
| 9 | warm | wet |
| 10 | w/c | wet |

| b | Regional Correlation Results: South Coast Month Anomaly Patterns | |
|---|---|---|
| Pattern | Temperature | Precipitation |
| 1 | cool | dry |
| 2 | warm | wet |
| 3 | warm | wet |
| 4 | cool | dry |
| 5 | warm | wet |
| 6 | w/c | wet |
| 7 | cool | dry |
| 8 | warm | dry |
| 9 | cool | dry |
| 10 | cool | wet |

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**Table 5.3a,b** Monthly mean climate and Basic Anomaly Patterns –Southwestern Islands Division 3 and Copper River Division 4. Winter Season (1956/57 to 1985/86) relationships between the ten Basic Anomaly Patterns and (a) Southwestern Islands Division 3, (b) Copper River Division 4 monthly mean temperature and precipitation characteristics; w/c=mixed temperature, w/d=mixed precipitation (see text for further explanation).

**a**

| Regional Correlation Results: Southwestern Islands Month Anomaly Patterns | | |
|---|---|---|
| Pattern | Temperature | Precipitation |
| 1 | warm | dry |
| 2 | warm | w/d |
| 3 | warm | dry |
| 4 | c/w | dry |
| 5 | w/c | dry |
| 6 | cool | wet |
| 7 | c/d | d/w |
| 8 | warm | wet |
| 9 | w/c | dry |
| 10 | w/c | dry |

**b**

| Regional Correlation Results: Copper River Month Anomaly Patterns | | |
|---|---|---|
| Pattern | Temperature | Precipitation |
| 1 | cool | dry |
| 2 | warm | dry |
| 3 | warm | wet |
| 4 | cool | dry |
| 5 | w/c | dry |
| 6 | warm | wet |
| 7 | cool | dry |
| 8 | warm | wet |
| 9 | w/c | d/w |
| 10 | warm | wet |

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In the Cook Inlet Division (Table 5.4a), warm patterns are either wet or mixed. The most prominent feature is below normal heights over the Aleutians. Cold patterns are dry. They tend to have above normal heights over the western Gulf of Alaska and north/northeast flow tendencies.

In the Bristol Bay region (Table 5.4b), cool patterns may be wet, dry, or mixed. A positive anomaly is generally positioned over the division. Warm patterns are also variable in terms of precipitation. Warm patterns generally include below normal heights to the south of the division or very small positive height departures.

Within the West Central Division (Table 5.5a), both the warm and the cool patterns tend to have variable precipitation characteristics. Warm patterns tend to have zonal flow characteristics. The cool patterns tend to be dominated by slightly below normal heights.

Interior Basin (Table 5.5b) cool patterns are wet or mixed. These cool patterns tend to have average or slightly above heights over the division and to the north. The warm patterns tend to be dry. Warm pattern flow is southerly or southwesterly.

Within the Arctic Drainage Division (Table 5.6a), both warm and cold patterns tend to have mixed precipitation characteristics. Warm patterns show very small height departures and the flow is generally zonal. Cold patterns have northerly flow tendencies.

The Gulf of Alaska sea surface temperatures are cooler than normal when BP1, BP2, BP4, BP6, BP9, and BP10 occur (Table 5.6b). BP7 is a mixed pattern. BP3, BP5, and BP8 are warm patterns. Cooler temperatures are generally seen with increased westerly/ northwesterly flow over the division.

## 5.4 Case Studies

In an effort to show how these associations between surface climate and atmospheric circulation might apply to specific events, six individual (warm, cold, normal temperature, wet, dry and normal

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**Table 5.4a,b** Monthly mean climate and Basic Anomaly Pattern associations–Cook Inlet Division 5 and Bristol Bay Division 6. Winter Season (1956/57 to 1985/86) relationships between the ten Basic Anomaly Patterns and (a) Cook Inlet Division 5, (b) Bristol Bay Division 6 monthly mean temperature and precipitation characteristics; w/c=mixed temperature, w/d=mixed precipitation (see text for further explanation).

**a** Regional Correlation Results: Cook Inlet Month Anomaly Patterns

| Pattern | Temperature | Precipitation |
|---|---|---|
| 1 | cool | d/w |
| 2 | warm | d/w |
| 3 | warm | wet |
| 4 | cool | dry |
| 5 | warm | w/d |
| 6 | warm | w/d |
| 7 | cool | dry |
| 8 | warm | dry |
| 9 | cool | dry |
| 10 | cool | wet |

**b** Regional Correlation Results: Bristol Bay Month Anomaly Patterns

| Pattern | Temperature | Precipitation |
|---|---|---|
| 1 | cool | d/w |
| 2 | warm | d/w |
| 3 | warm | dry |
| 4 | cool | dry |
| 5 | warm | wet |
| 6 | cool | dry |
| 7 | cool | wet |
| 8 | warm | dry |
| 9 | cool | d/w |
| 10 | cool | dry |

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**Table 5.5a,b** Monthly mean climate and Basic Anomaly Pattern associations–West Central Division 7 and Interior Basin Division 8. Winter Season (1956/57 to 1985/86) relationships between the ten Basic Anomaly Patterns and (a) West Central Division 7, (b) Interior Basin Division 8 monthly mean temperature and precipitation characteristics; w/c=mixed temperature, w/d=mixed precipitation (see text for further explanation).

**a**

Regional Correlation Results: West Central Month Anomaly Patterns

| Pattern | Temperature | Precipitation |
|---|---|---|
| 1 | cool | wet |
| 2 | warm | dry |
| 3 | warm | dry |
| 4 | c/w | d/w |
| 5 | warm | d/w |
| 6 | cool | dry |
| 7 | c/w | d/w |
| 8 | warm | wet |
| 9 | warm | d/w |
| 10 | cool | dry |

**b**

Regional Correlation Results: Interior Basin Month Anomaly Patterns

| Pattern | Temperature | Precipitation |
|---|---|---|
| 1 | cool | wet |
| 2 | warm | dry |
| 3 | warm | dry |
| 4 | cool | d/w |
| 5 | warm | d/w |
| 6 | cool | w/d |
| 7 | cool | w/d |
| 8 | warm | wet |
| 9 | warm | dry |
| 10 | cool | wet |

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**Table 5.6a,b** Monthly mean climate and Basic Anomaly Patterns –Arctic Drainage Division 9 and Gulf of Alaska Division 10. Winter Season (1956/57 to 1985/86) relationships between the ten Basic Anomaly Patterns and (a) Arctic Drainage Division 9 temperature and precipitation, (b) Gulf of Alaska Division 10 monthly mean sea surface temperature; w/c=mixed temperature, w/d=mixed precipitation (see text for further explanation).

**a**

Regional Correlation Results: Arctic Drainage Month Anomaly Patterns

| Pattern | Temperature | Precipitation |
|---|---|---|
| 1 | c/w | wet |
| 2 | warm | d/w |
| 3 | cool | w/d |
| 4 | c/w | d/w |
| 5 | warm | d/w |
| 6 | cool | w/d |
| 7 | cool | d/w |
| 8 | warm | wet |
| 9 | warm | d/w |
| 10 | cool | w/d |

**b**

Regional Correlation Results: Gulf of Alaska Month Anomaly Patterns

| Pattern | Temperature | Precipitation |
|---|---|---|
| 1 | cool | na |
| 2 | cool | na |
| 3 | warm | na |
| 4 | cool | na |
| 5 | warm | na |
| 6 | cool | na |
| 7 | c/w | na |
| 8 | warm | na |
| 9 | cool | na |
| 10 | cool | na |

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precipitation) events from the Alaska winter season were examined.

Warm Event: January 1981 in the Interior Basin is the most extreme warm episode in the winter record (Fig. 5.2). The warm period occurred near the end of a downward interannual trend in the division's January temperature record. The month was $15°C$ warmer than the thirty-year mean, $17.5°C$ greater than January 1980, and $20°C$ greater than January 1982. Within the same 1980/81 season, October, February and November were also above average. December was extremely cold and March was above normal. The Gulf of Alaska SST's (Fig 4.38) were cooler than normal from November 1980 until February 1981. Both February and March 1981 were slightly warmer than normal. A breakdown of the January 1981 temperature record into pentads (five-day mean values in anomaly form) (Fig. 5.3) shows that the entire month was well above the thirty-year January mean of $-22.4°C$. As there was not a large amount of variation from pentad to pentad, it may be assumed that the warming was persistent throughout the month and not just the result of a single short-lived synoptic event.

The thirty-year mean January $700mb$ circulation (Fig. 5.2) is characterized by a trough over the North Pacific. A ridge is positioned along the mountain ranges of the North American West Coast. The ridge extends diagonally from SE to NW across Alaska's interior. Assuming geostrophy, this mean pattern results in flow from the south or southwest into the Interior Basin. From the classification analysis of Chapter 3, January 1981 was designated a Basic Anomaly Pattern 2 month (Fig. 5.4). This basic pattern consists of below normal heights extending from the Gulf of Alaska into the Interior region. Above normal heights are located in central interior Canada. This pattern indicates more intensified south/southeast flow into the interior. Basic Anomaly Pattern 2 (BP2) was also classified as a warm pattern for the Interior Division (Table 5.5b). Pentad (Fig. 5.5) or five-day anomaly maps (see Chapter 3 for calculation) available for January 1981 are similar to the monthly anomaly pattern (Fig. 5.4). They indicate below normal heights over the Gulf of Alaska region and

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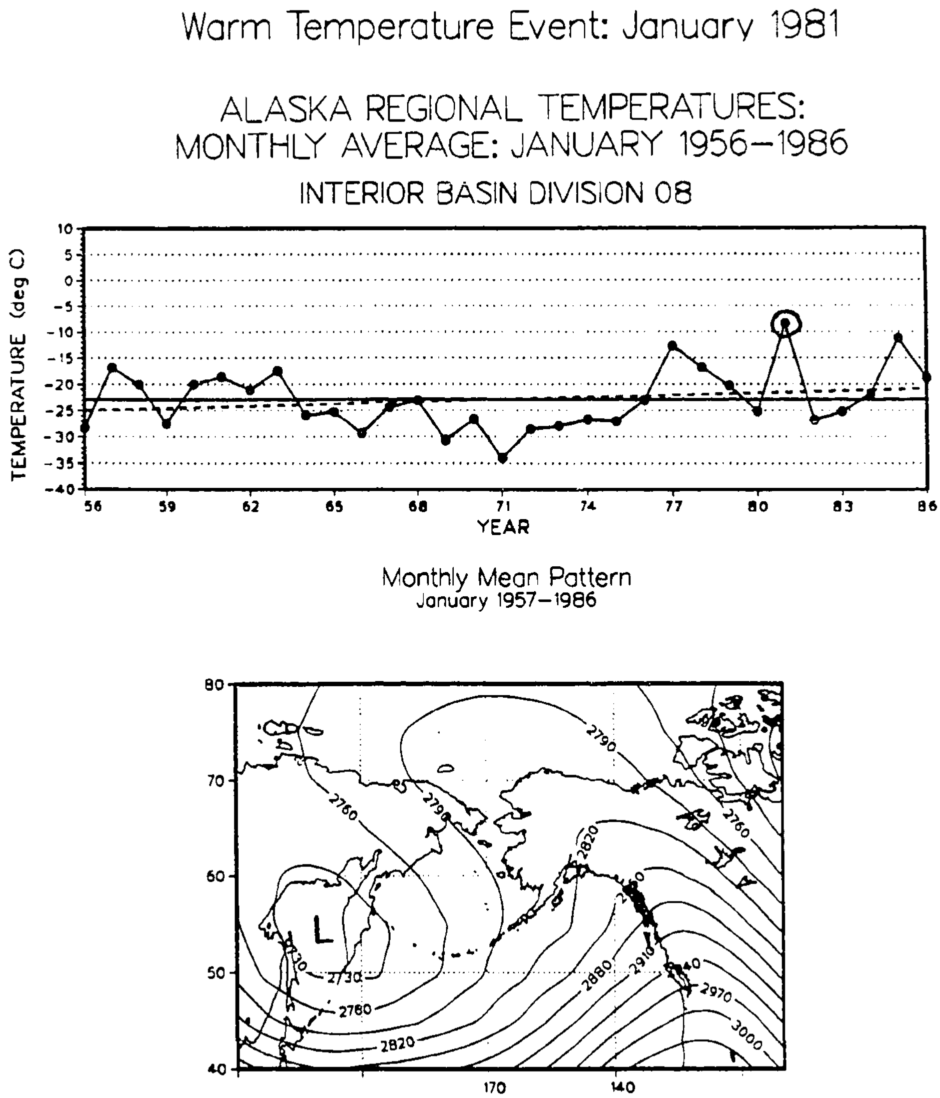


**Figure 5.2** January monthly average temperature–Interior Basin Division 8 and thirty-year mean January $700mb$ circulation pattern. contours on map are $30m$; January 1981, the warm event, is circled in the temperature plot.

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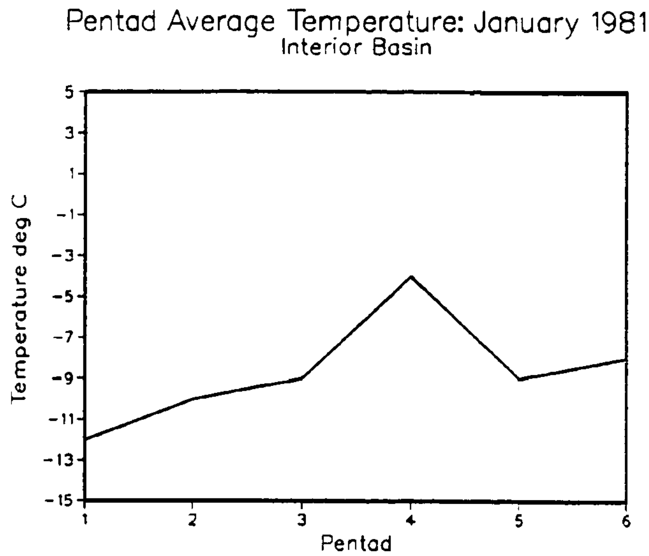


**Figure 5.3** January 1981 pentad (five-day) average temperatures. Interior Basin Division 9; pentad dates: 1= Dec. 30-Jan. 3, 2= Jan. 4-8, 3= Jan. 9-13, 4= Jan. 14-18, 5= Jan. 19-23, 6= Jan. 24-28.

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above normal heights over Canada and portions of the Southeastern Division of Alaska. Once again the flow would be an enhanced version of the mean south/southeast/southwest flow.

Several possible reasons for this extremely warm event exist. We consider the two primary factors that contribute in a broad sense to warmer Alaska interior temperatures– the amount of solar radiation, and the heat transport from the south (Ohtake, 1989). As solar radiation is close to its annual minimum during January, its contribution to the heat balance of the region. From the circulation patterns of January 1981, it is evident that the flow pattern is predominantly from the south, southwest, or southeast. The $700mb$ patterns, both mean and anomaly, show no indication of strong zonal flow. This suggests that meridianal heat transport is dominant. Because of the position of the enhanced ridge/trough circulation the Interior Division is in the path of more intense warm advection from the south. This warm advection was the main cause of the extremely warm temperature event.

Cold Event: Copper River February 1979 was chosen to represent the anomalously cold event because it is one of the most abnormal of all the cold episodes in any division (Fig. 5.6). February 1979 was $12°C$ colder than the thirty-year mean of $-15°C$, $13°C$ colder than February 1978 and $17°C$ colder than February 1980. Other months during the 1978/79 winter season had monthly mean temperatures equal to or slightly above average. A five-day (pentad) breakdown of February 1979's temperatures (Fig. 5.7) shows that the entire month was $5°C$ or more below the thirty-year February mean value. However, there is a fairly large fluctuation in temperatures from one pentad (five-day period) to the next. This suggests that while the cold did exist for the entire month, its intensity may have been influenced by a higher frequency circulation component.

The mean $700mb$ February circulation (Fig. 5.6) has a broad closed low pressure area over Kamchatka Peninsula. A ridge is also positioned over the west coast mountains of British Columbia and southeast Alaska extending to $140°W, 64°N$. The mean flow into the Copper River Division is from the southwest. In our classification analysis, February 1979 was designated a BP4 month.

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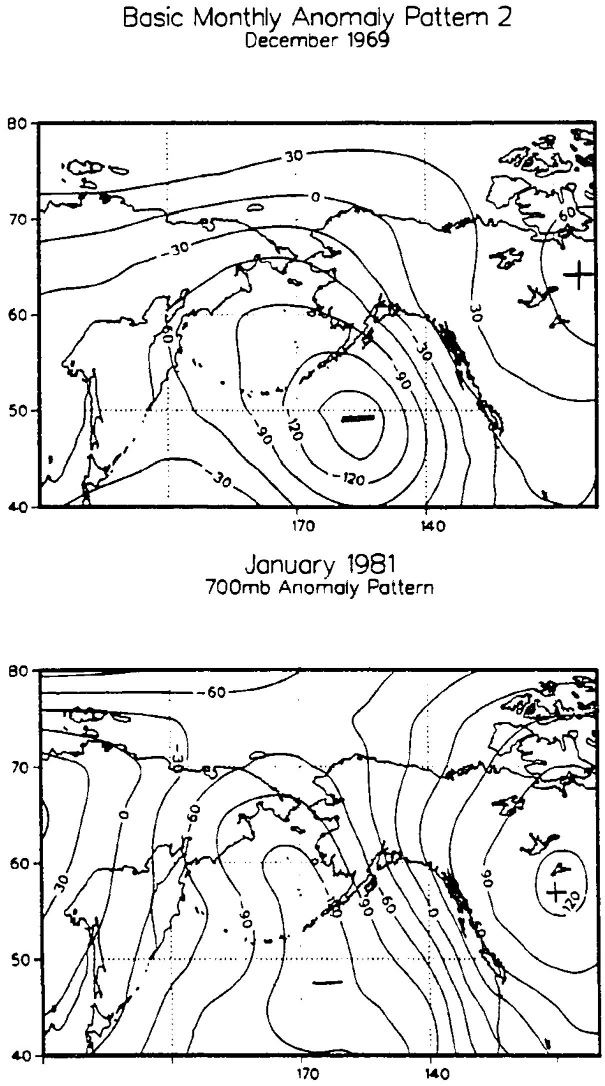


**Figure 5.4** Basic Anomaly Pattern 2 and January 1981 $700mb$ anomaly pattern. contours are $30m$ departures from the thirty-year mean.

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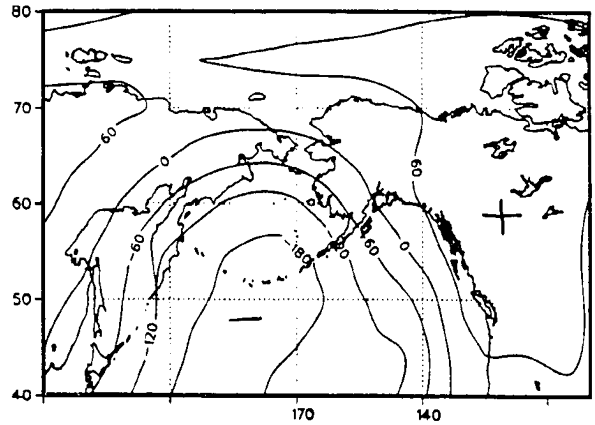
Pentad 2
January 4–8, 1981




Pentad 4
January 14–18, 1981

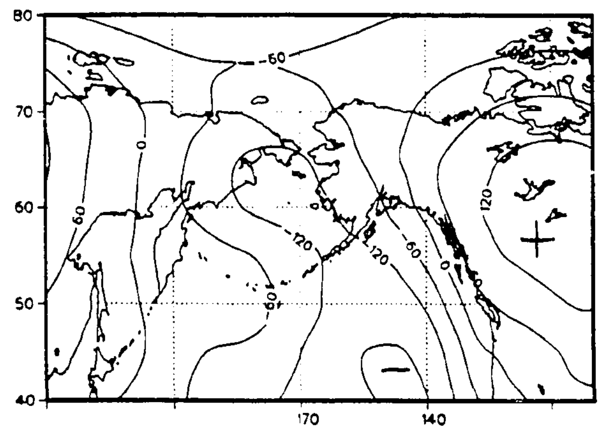



**Figure 5.5** $700mb$ anomaly maps for January 1981. Pentad 2 and Pentad 4 (other pentads are incomplete); contours are $60m$ departures from the thirty-year pentad mean.

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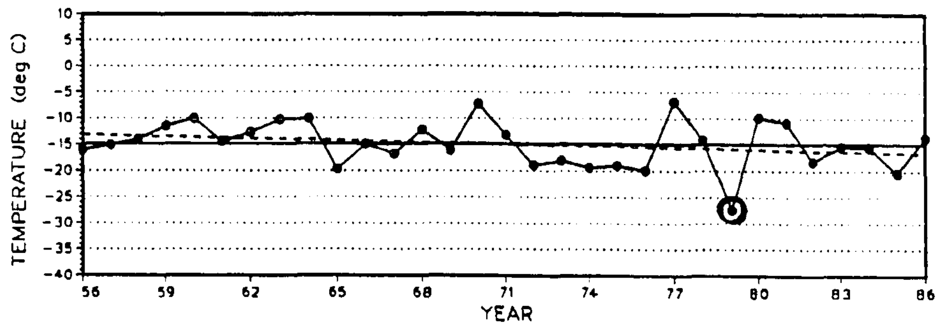
Cold Temperature Event: February 1979

ALASKA REGIONAL TEMPERATURES:
MONTHLY AVERAGE: FEBRUARY 1956–1986

COPPER RIVER DIVISION 04




Monthly Mean Pattern
February 1957–1986

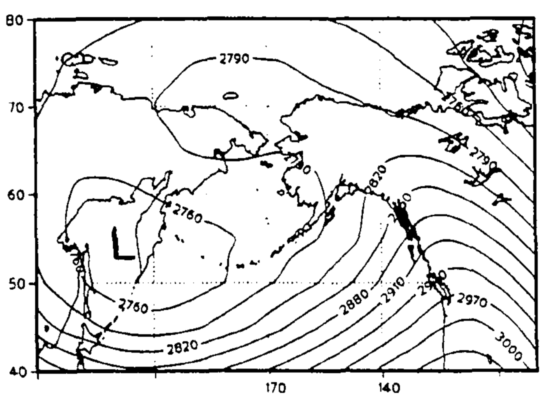



**Figure 5.6** February monthly average temperature–Copper River Division 4 and thirty-year mean February $700mb$ circulation pattern. contours on map are $30m$; February 1979, the cold event, is circled in the temperature plot.

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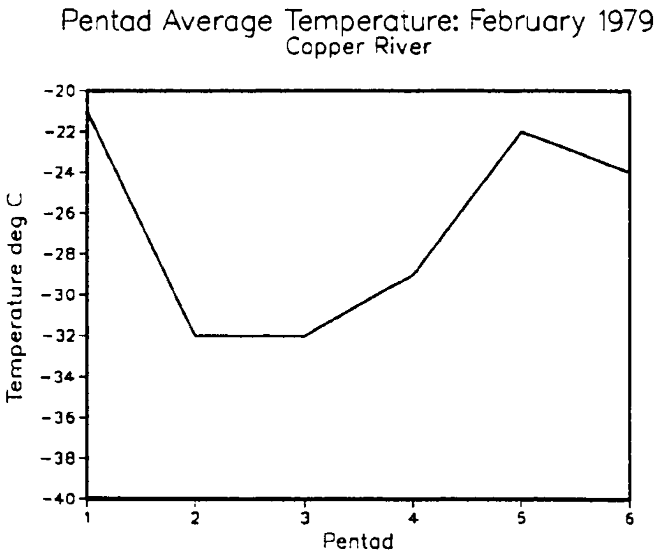


**Figure 5.7** February 1979 pentad (five-day) average temperatures. Copper River Division 4; pentad dates: 1= Jan. 29-Feb. 2, 2= Feb. 3-7, 3= Feb. 8-12, 4= Feb. 13-17, 5= Feb. 18-22, 6= Feb. 23-27.

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In the earlier sections of this chapter, BP4 (Fig. 5.8) was designated to be a cold pattern for this region (Table 5.3b). The most prominent feature on the anomaly map is an intense positive anomaly centered over the Aleutians, extending from the central Gulf of Alaska to Asia and north to the Chukchi Sea region. This pattern indicates enhanced northerly or northeasterly flow into the Copper River region. Pentad anomaly maps (Fig. 5.9) for February 1979 are similar to the basic anomaly pattern in principle, but there is some variation in the positions of the anomaly features. P1 (pentad 1) has above normal heights from the central Gulf of Alaska, west and north to the edge of the study area. P2 also has a large positive anomaly region, but its strongest departures are shifted west to the central North Pacific. A negative anomaly has filled in the eastern sector of the map and its center is just east of the Copper River region. P3 shows the positive anomaly further east than in P2. The negative anomaly has weakened and shifted east of its position in P2. P4 shows a somewhat weaker positive anomaly and a stronger negative anomaly. The negative anomaly has returned to its position of P2. P5 shows an even weaker positive anomaly, but the negative anomaly has shifted east to its position in P1. P6 has a negative anomaly over the Aleutians and a large positive anomaly over Siberia and northwestern Alaska. The negative anomaly over the northeast Gulf of Alaska has shifted west again to its position in P3.

Combining the two elements of atmospheric circulation and climate leads to the suggestion of two causal mechanisms for this cold event. First, the Basic Anomaly Pattern associated with February 1979 indicates that the flow into the region was from the north or northeast. This would result in cold advection or the transport of cold air from the Interior Basin of Alaska or western Canada to the Copper River Basin. As the division is a basin/mountain region, the cold air could have been trapped in the lower elevations making the temperatures cold throughout the month. It is also important to note that in winter, temperature falls are not as rapid as rises because, in addition to their associations with advective processes, the decreases are also strongly tied to the lengthy process of radiative cooling (Fathauer, pers. comm.).

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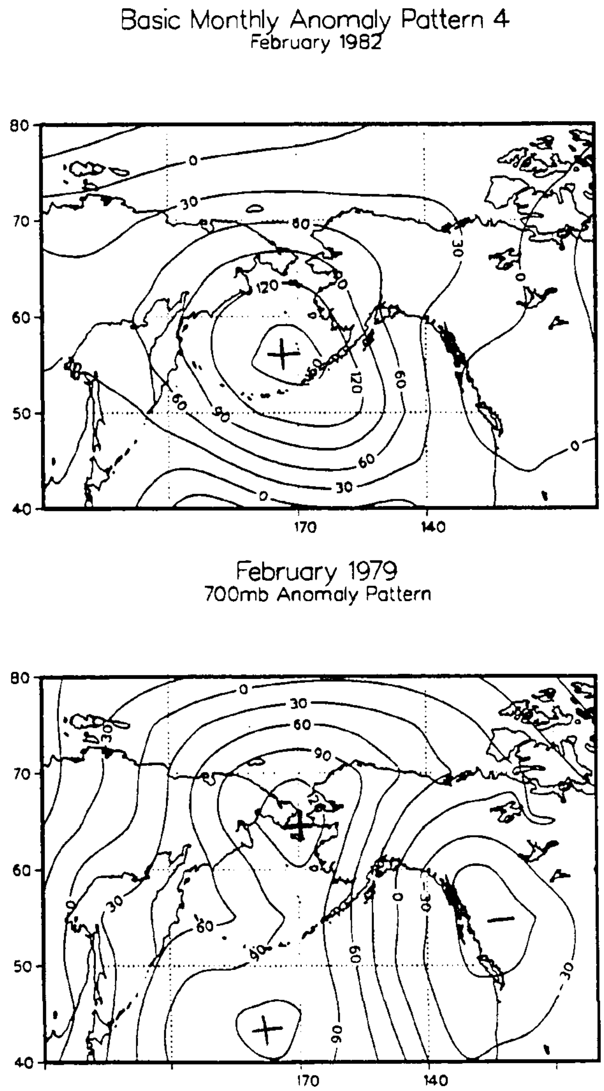


**Figure 5.8** Basic Anomaly Pattern 4 and February 1979 $700mb$ anomaly pattern. contours are $30m$ departures from the thirty-year mean.

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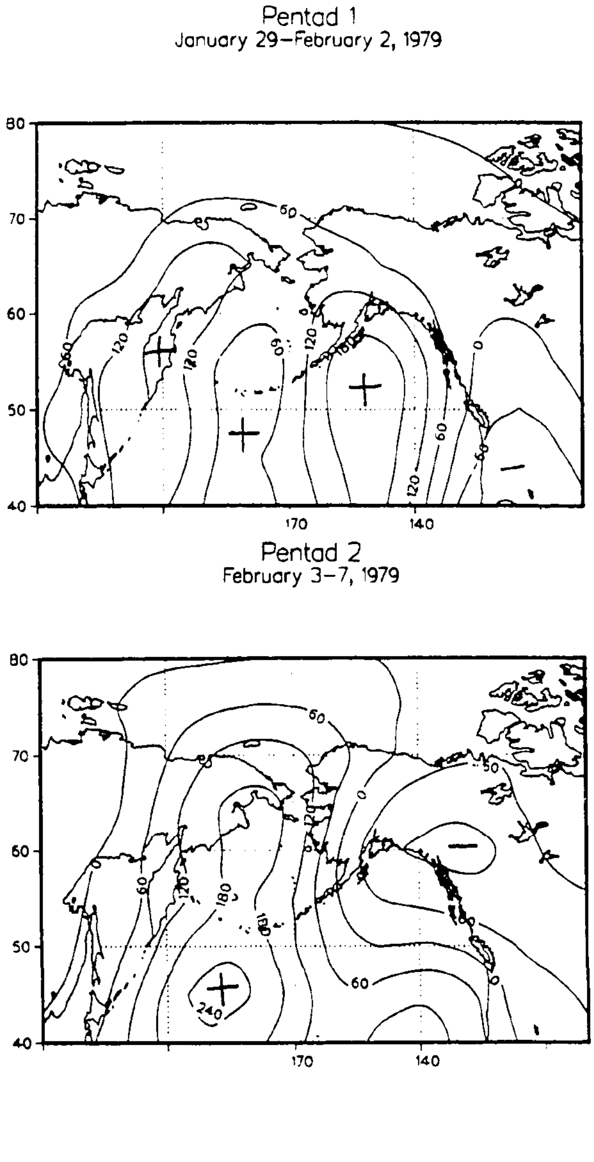


**Figure 5.9** 700*mb* anomaly maps for February 1979. Pentad 1 (P1) and Pentad 2 (P2); contours are 60*m* departures from the thirty-year pentad mean.

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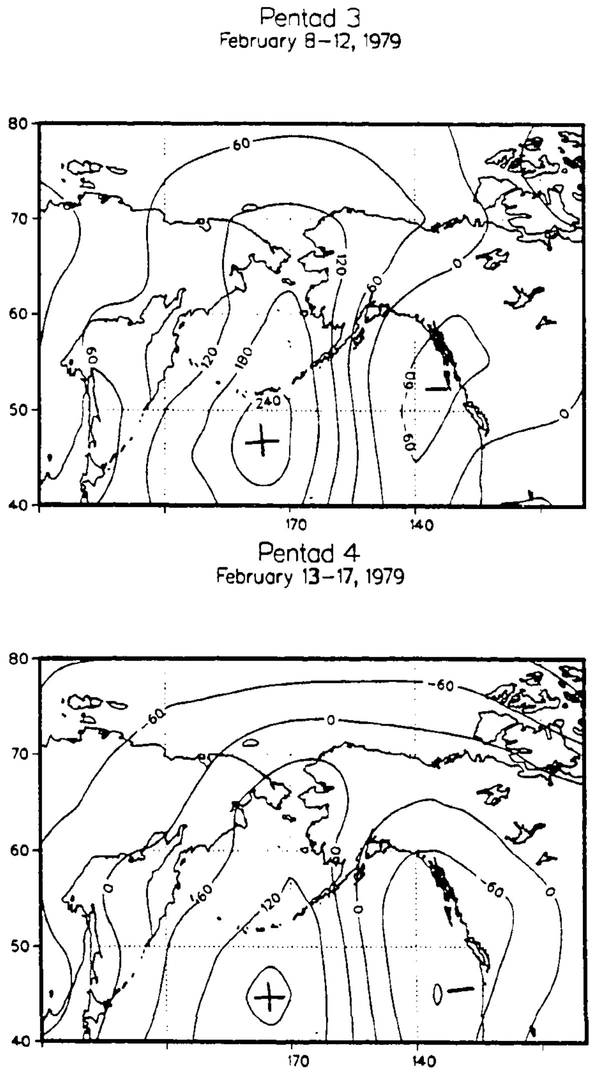


**Figure 5.9cont'd** 700*mb* anomaly maps for February 1979. Pentad 3 (P3) and Pentad 4 (P4); contours are 60*m* departures from the thirty-year pentad mean.

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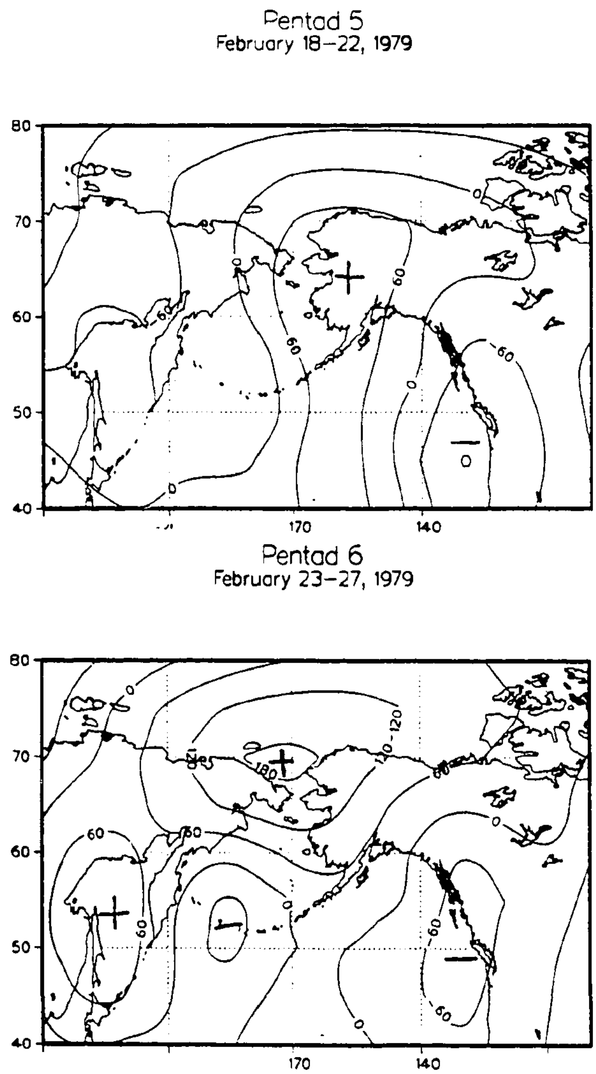


**Figure 5.9cont'd** 700$mb$ anomaly maps for February 1979. Pentad 5 (P5) and Pentad 6 (P6); contours are 60$m$ departures from the thirty-year pentad mean.

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The second mechanism acts together with the first, but it seems to account for the shorter-period variations in cold temperatures within the month. The fluctuation seems to be tied to the position of the positive and negative anomaly features on the pentad charts. When the positive anomaly is shifted to its western position, the flow into the Copper River Basin develops a northeast component. This results in cold air being advected in from central Canada and the coldest pentad temperatures. When the positive anomaly is shifted east over or close to the eastern Gulf of Alaska as in P1, P5, and P6, the flow into the Copper River Basin is from the north or northwest. Although this would still indicate generally cold advection, the cold is is obviously not as intense as during P2 and P4 because P1, P5, and P6 are the warmest pentads. From this it can be concluded that northeast flow (cold, dry airmass source region) is greatly responsible for the extreme cold within this cold event.

Normal Temperature Event: Southwestern Islands October 1961 was chosen to represent a normal land-based temperature situation (Fig. 5.10). In this case, normal is defined to be a value equal to the thirty-year mean temperature value for the specific month/division in question. The mean temperature for October 1961 in the Southwestern Islands was $4.8°C$. October 1960 and October 1962 were also close to the thirty-year mean value. November 1961 and December 1961 were equal to their respective thirty-year mean values as well. Sea surface temperatures in the Gulf of Alaska were cooler than normal throughout the 1961/62 season. A pentad breakdown of the October 1961 land-based temperatures (Fig. 5.11) shows a 5° variation from the warmest pentads (P2 and P4) to the coldest pentad (P6). The temperature seems to oscillate from warm to cool every five days suggesting an association with the regular "passage" period of large-scale waves in the westerlies (Fathauer, pers. comm.).

The mean October $700mb$ circulation pattern (Fig. 5.10) is characterized by zonal flow across the western and Central Pacific Ocean. There is a trough and ridge feature over mainland Alaska and the eastern Gulf of Alaska. The Southwestern Islands are in the region of zonal westerly flow. October 1971 was defined to be a Basic Anomaly Pattern 7 (BP7) month in the classification process

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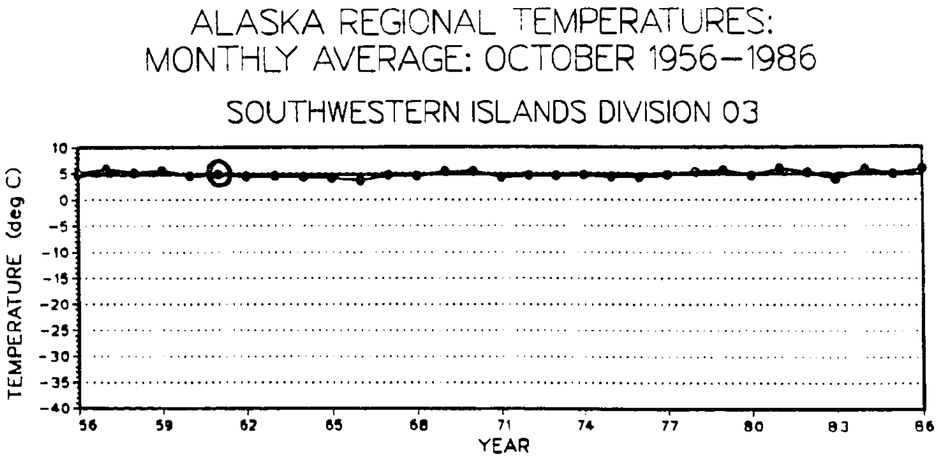
# Normal Temperature Event: October 1961



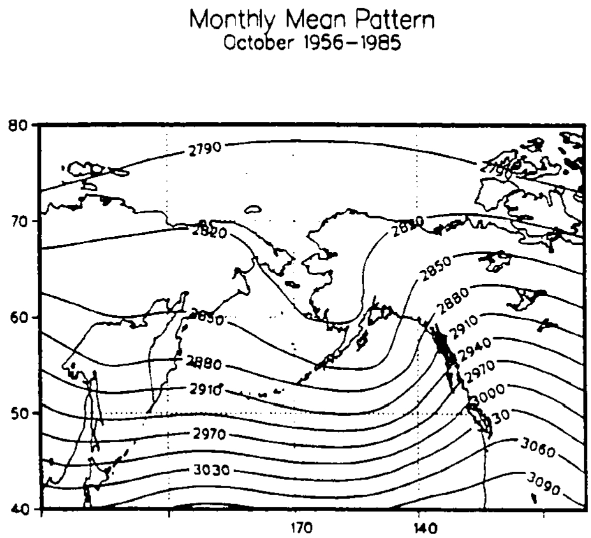




**Figure 5.10** October monthly average temperature–Southwestern Islands Division 3 and thirty-year mean October $700mb$ circulation pattern. contours on map are $30m$; October 1961, the normal event, is circled in the temperature plot.

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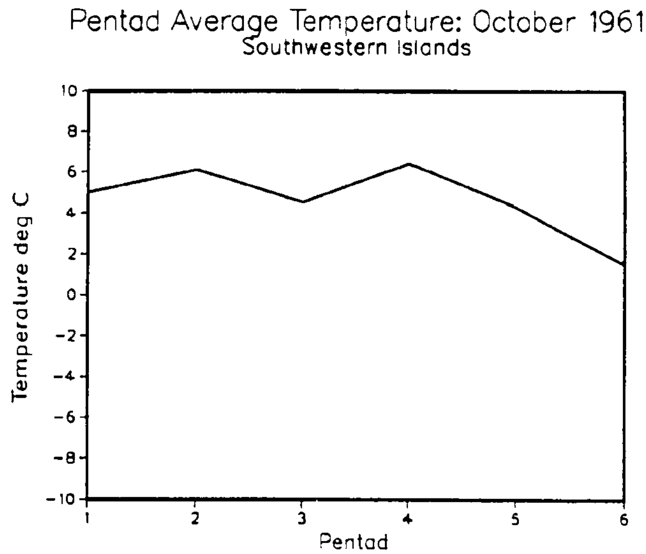


**Figure 5.11** October 1961 pentad (five-day) average temperatures. Southwestern Islands Division 3; pentad dates: 1= Oct. 1-5, 2= Oct. 6-10, 3= Oct. 11-15, 4= Oct. 16-20, 5= Oct. 21-25, 6= Oct. 26-30.

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of Chapter 3. From Table 5.3a it can be seen that this basic pattern is mixed climatically in the Southwestern Islands Division. The pattern may result in warm or cool conditions. There are two main features that make up the basic pattern (Fig. 5.12). The first is a positive anomaly centered over the East Pacific. It extends northwest into Asia. The second is a weak negative anomaly positioned over the west coast of British Columbia and southeast Alaska. The western islands of the SWI division are in the zone of southerly flow and the more eastern islands are in the zone of northerly flow. Individual pentads from October 1971 are shown in Fig. 5.13. P1 has below normal heights over the Islands with the flow pattern indicating a mixture of northerly flow in the west and southwesterly flow in the eastern islands. P2 is characterized by a large positive anomaly situated over the Aleutians resulting in a combination of southerly flow (western islands) and northerly flow (eastern islands). P3 has very weak anomaly features, but the Islands are positioned in an area of slightly above normal heights. P4 has a strong positive anomaly over the Kamchatka Peninsula and the Bering Sea. The positive anomaly is balanced by a strong negative in the Gulf of Alaska. Flow over the Islands has a southerly tendency. P5 shows a broad positive anomaly stretching across the Pacific Ocean. P6 is dominated by a broad, weak positive anomaly in the same region as the feature in P5.

In combining the pentad temperatures and circulation patterns, we note the large variability in position and intensity of the phenomena that occur within a so-called normal month. In this case, the higher frequency features are more informative than the low frequency monthly-scale feature. The results of the pentad examination suggest that the only reason this month was a "normal" month is that the see-saw oscillations of the shorter-time scale behavior cancelled each other out during the month-scale averaging process. A pentad-based summary of this month's synoptic climatology is as follows: dominant south/southwest flow with positive anomaly in Gulf of Alaska area corresponds to warm temperatures; zonal flow corresponds to lower temperatures; and northerly flow corresponds to lowest temperatures.

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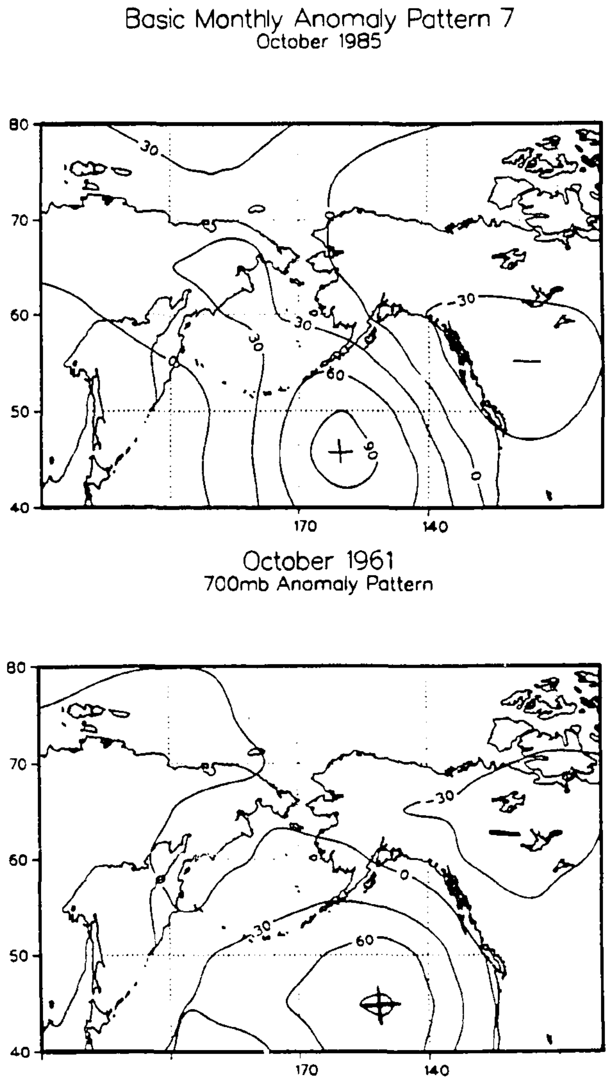


**Figure 5.12** Basic Anomaly Pattern 7 and October 1961 $700mb$ anomaly pattern. contours are $30m$ departures from the thirty-year mean.

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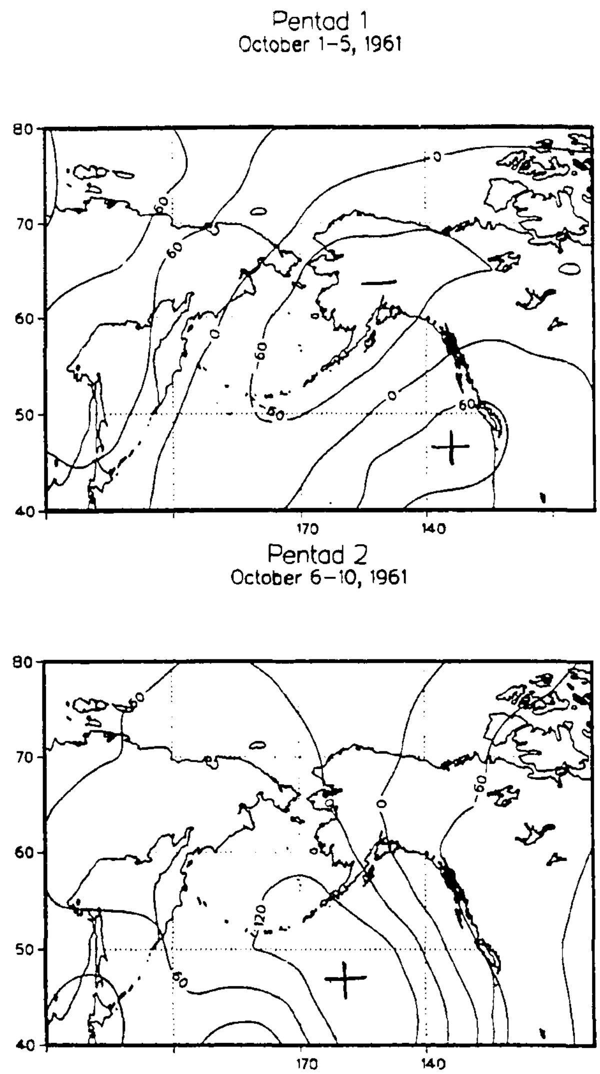


**Figure 5.13** 700$mb$ anomaly maps for October 1961. Pentad 1 (P1) and Pentad 2 (P2); contours are 60$m$ departures from the thirty-year pentad mean.

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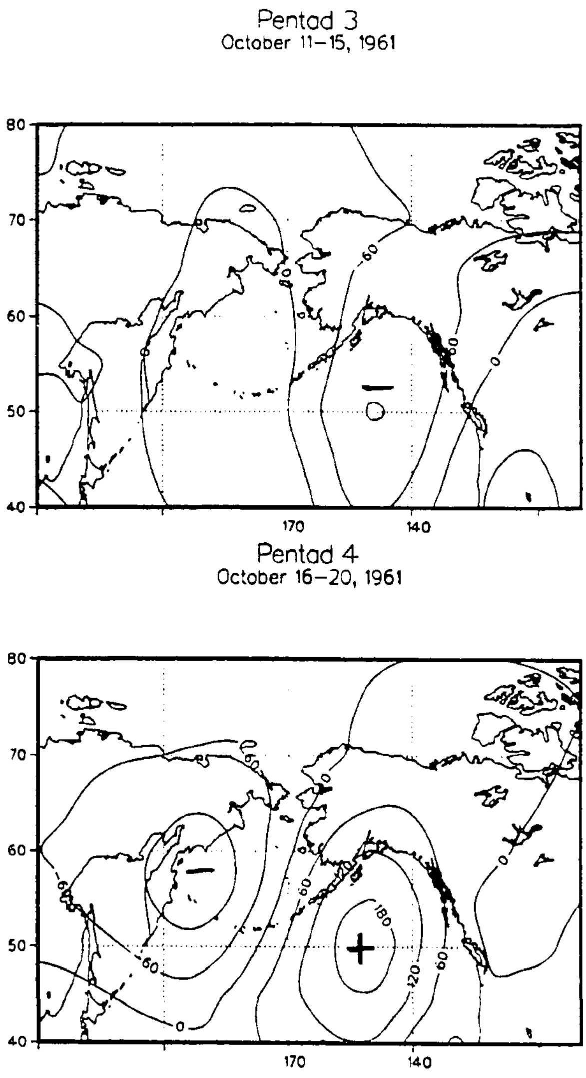


**Figure 5.13cont'd** 700*mb* anomaly maps for October 1961. Pentad 3 (P3) and Pentad 4 (P4); contours are 60*m* departures from the thirty-year pentad mean.

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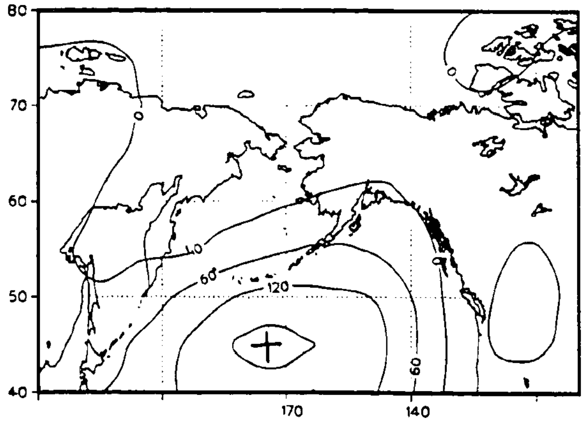
Pentad 5
October 21–25, 1961




Pentad 6
October 26–30, 1961

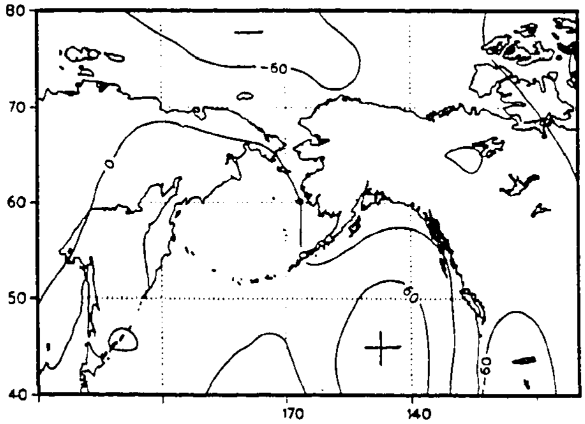



**Figure 5.13cont'd** 700*mb* anomaly maps for October 1961. Pentad 5 (P5) and Pentad 6 (P6); contours are 60*m* departures from the thirty-year pentad mean.

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Wet Event: The Southeastern Division October 1974 (Fig. 5.14) month was chosen to represent a wet event because it is one of the most extreme wet periods in the Alaska records. There are other wet events in either the South Coast Division or the Southeastern Division that are also classified as extreme events, but the corresponding $700mb$ data were not available. The monthly-mean precipitation for October 1974 in the Southeastern Division was $630mm$. This was $330mm$ greater than that of October 1973 and $430mm$ greater than the October 1975 value. The extreme value occurred close to the end of a decade of below normal precipitation. A pentad breakdown of the October 1974 precipitation (Fig. 5.15) shows two distinct peaks. Pentad 5 (P5) is the wettest extreme. It is $40mm$ wetter than the second highest peak during the month.

The mean October $700mb$ pattern shown in Fig. 5.14 places the Southeastern division under a ridge. The flow is onshore from the south and southwest. The October 1974 $700mb$ anomaly pattern has been classified as a Basic Anomaly Pattern 3 (BP3) case (Fig. 5.16, Table 5.2a). This basic pattern has three main features. The first is a broad positive anomaly over the northern section of eastern Europe and Asia. The second is a strong negative anomaly centered over the Pacific near $170°W, 45°N$. The third is a positive anomaly positioned over the west coast of British Columbia and Washington. The overall anomaly pattern results in enhanced south/southwest flow into the Southeastern region of Alaska. A pentad or five-day breakdown of October 1974 circulation is shown in Fig. 5.17. Below normal heights and northerly flow were the dominant characteristics of P1 in the Southeast region. P2 shows normal to above normal heights resulting in a west/southwest flow tendency. P5 shows an intense negative anomaly in the eastern Pacific/ western Gulf of Alaska sector and a strong positive anomaly over the Southeastern Division. This pattern is most similar to the monthly mean pattern. P6 places the Southeast under slightly below normal heights with flow from the south/southeast quadrants. P3 and P4 have not been included in the circulation patterns due to incomplete data during the associated periods.

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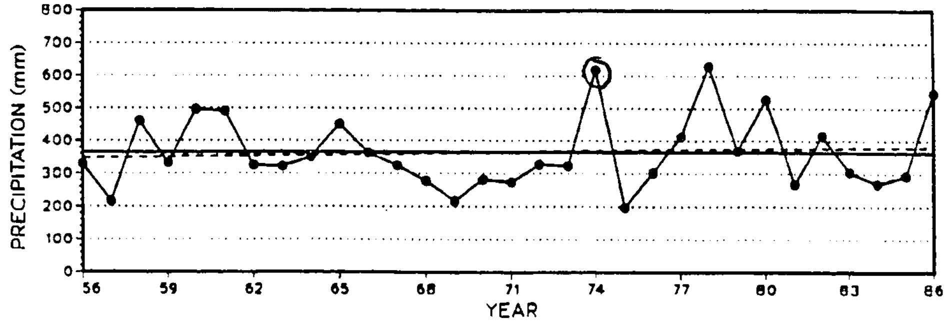
Wet Precipitation Event: October 1974

ALASKA REGIONAL PRECIPITATION:
MONTHLY AVERAGE: OCTOBER 1956–1986

SOUTHEASTERN DIVISION 01




Monthly Mean Pattern
October 1956–1985

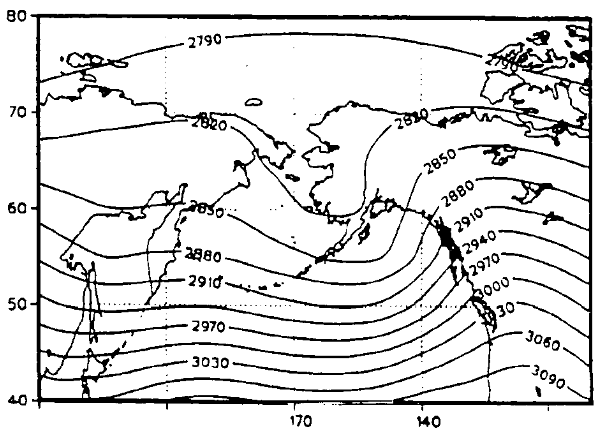



**Figure 5.14** October monthly average precipitation–Southeastern Division 1 and thirty-year mean October 700$mb$ circulation pattern. contours on map are 30$m$; October 1974, the wet event, is circled in the precipitation plot.

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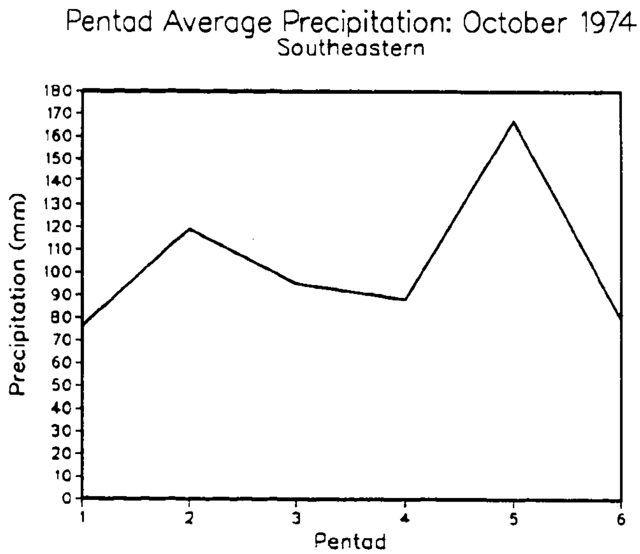


**Figure 5.15** October 1974 pentad (five-day) average precipitation. Southeastern Division 1; pentad dates: 1= Oct. 1-5, 2= Oct. 6-10, 3= Oct. 11-15, 4= Oct. 16-20, 5= Oct. 21-25, 6= Oct. 26-30.

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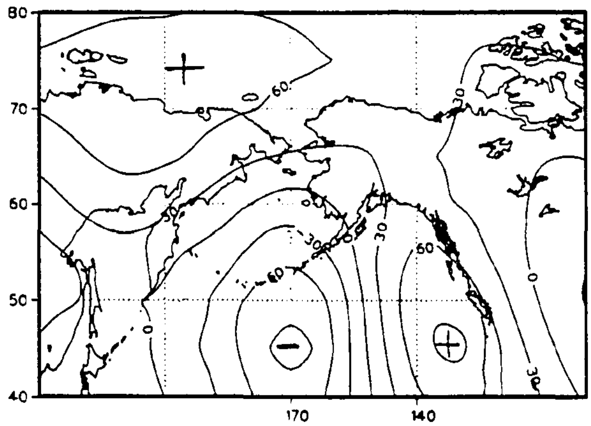
Basic Monthly Anomaly Pattern 3
November 1959




October 1974
700mb Anomaly Pattern

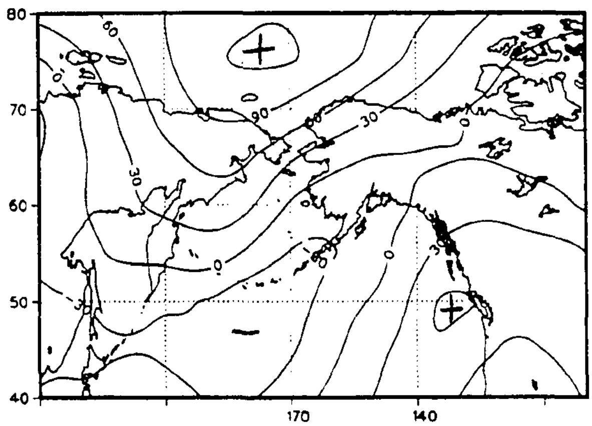



**Figure 5.16** Basic Anomaly Pattern 3 and October 1974 $700mb$ anomaly pattern. contours are $30m$ departures from the thirty-year mean.

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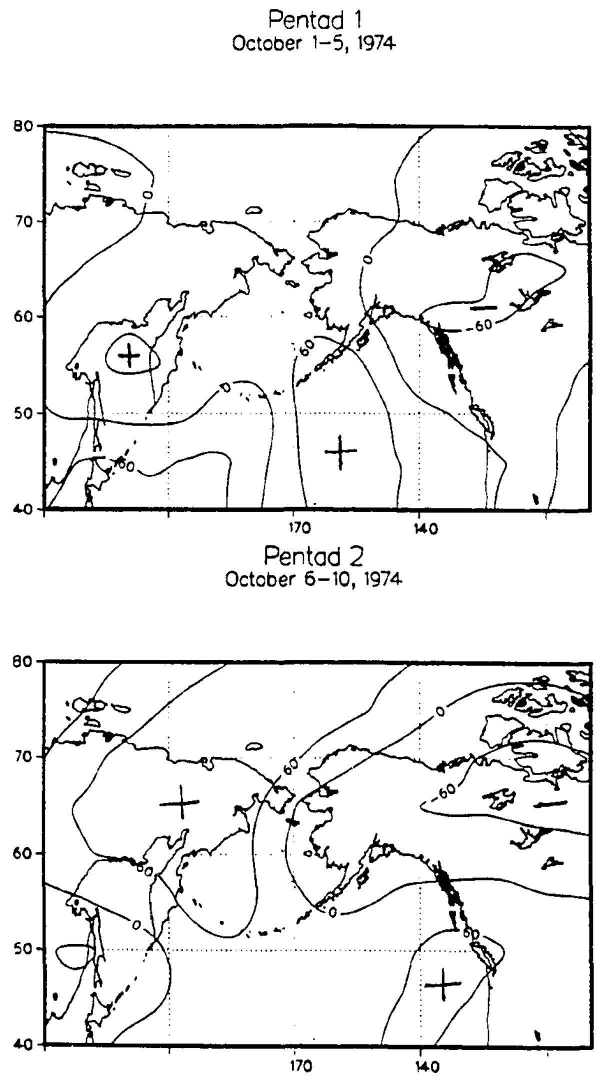


**Figure 5.17** 700$mb$ anomaly maps for October 1974. Pentad 1 (P1) and Pentad 2 (P2); contours are 60$m$ departures from the thirty-year pentad mean.

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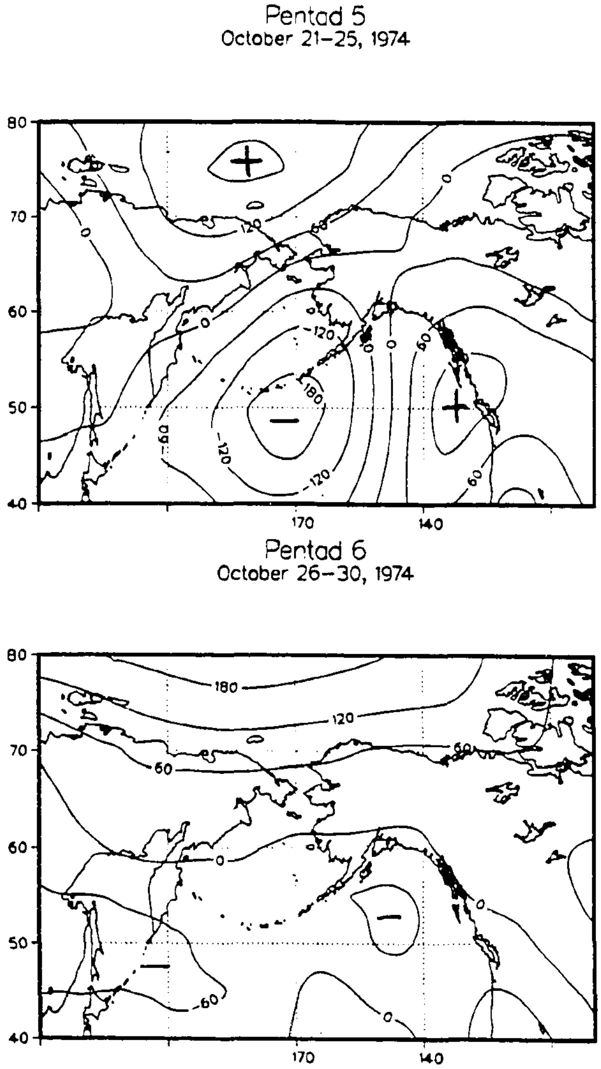


**Figure 5.17cont'd** 700*mb* anomaly maps for October 1974. Pentad 5 (P5) and Pentad 6 (P6); contours are 60*m* departures from the thirty-year pentad mean.

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This extremely wet month appears to be tied to the intensity of the $700mb$ features, the Gulf of Alaska sea surface temperatures and the dominant flow direction. The entire 1974/75 winter season had above normal Gulf of Alaska sea surface temperatures which might have enhanced the west coast atmospheric ridge by warming the atmosphere. The warmer SST's would also increase the evaporative flux of moisture into the atmosphere. The enhanced southerly/southwesterly flow due to the strengthened ridge aloft and the increased moisture flux would both contribute favorably towards increasing precipitation in the Southeastern Division. A secondary contribution of the warm SST's to the increase in precipitation might be an enhancement of any already existing unstable conditions in the area surrounding the Southeastern Division. If the greater instability persisted, it would lead to stronger flow, greater onshore moisture transport at the $700mb$ level, and larger monthly mean precipitation values.

Although the monthly-mean anomaly pattern is indicative of a wet month because of its associated southwesterly flow, the pentad charts seem to be more closely related to the precipitation behavior. The driest pentads were those with weak anomalies and southeastly or northerly flow over the Southeastern Division at the $700mb$ level. The wettest pentads have a strong negative anomaly over the western Gulf of Alaska and southerly or southwesterly flow over the Southeastern region at $700mb$.

<u>Dry Event:</u> South Coast February 1979 (Fig. 5.18) was chosen to be the dry event for discussion. The mean February precipitation is $160mm$. February 1979 was $144mm$ dryer than this with a mean value of $26mm$. The $26mm$ value makes February 1979 the dryest month in the February South Coast record. The Februarys immediately preceding and following the dry event were wetter than normal. Within the 1978/79 season, November, January, and March were also much dryer than normal. A division of the month into pentads shows that most of the five-day periods had low mean

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precipitation values (Fig. 5.19). The wettest pentads were PI and P3 with $11mm$. The dryest pentad was P6 with $4mm$. A continuous decrease in mean precipitation values began with P3.

The $700mb$ circulation for February (Figs. 5.18, 5.20, and 5.21) was discussed in detail as part of the warm event section of this chapter. The thirty year mean February pattern shows a ridge over the South Coast Division. Flow into the division is from the south off the ocean. February 1979 is a Basic Anomaly Pattern 4 (BP4) month (Fig. 5.20, Table 5.2b). This pattern is characterized by an intense positive anomaly centered over the southern tip of the Alaskan Peninsula. This indicates northerly flow into the South Coast Division. Individual pentads (Fig. 5.21) show an oscillation between positive anomaly heights and negative anomaly heights over the South Coast region. The resulting flow suggested is in general from the north/northwest/northeast.

Combining the precipitation data and the anomaly charts for February 1979 suggests that the precipitation intensity is strongly influenced by the period's flow regime. The division is driest when the negative anomaly over the southeast Alaska is in its western position. When the positive anomaly over the Aleutian Islands is at its most intense and the negative anomaly is over the northeast Gulf of Alaska, the division is wettest. A second factor leading to the low precipitation might be the lower than normal Gulf of Alaska SST's that were present during the 1978/79 winter. The reduced atmosphere-ocean thermal contrast would result in greater atmospheric stability, less water vapor flux to the atmosphere, and less storm activity. This in turn would result in weaker flow, weaker onshore moisture transport, and finally, lower than normal precipitation values.

<u>Normal Precipitation Event:</u> Bristol Bay December 1981 (Fig. 5.22) is the so-called "normal" month to be examined. The mean precipitation value for December in the Bristol Bay Division is $44mm$. The monthly mean values of December 1980 and 1982 are also close to this mean value. Within the 1981/82 season, January and March are slightly above their respective normal values. Only February of that season is dryer than its thirty year mean. Mean pentad precipitation (Fig. 5.23) for December 1981 ranges from a high of $16mm$ to a low of $6mm$. There is quite a bit

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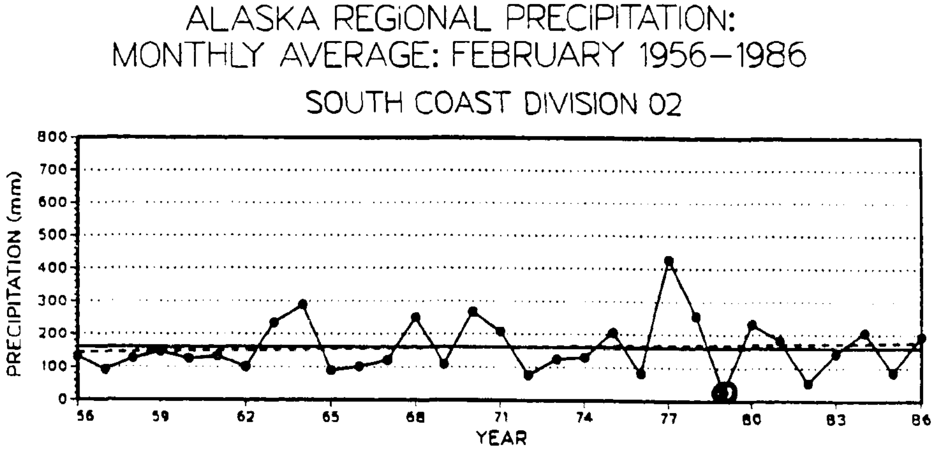
Dry Precipitation Event: February 1979



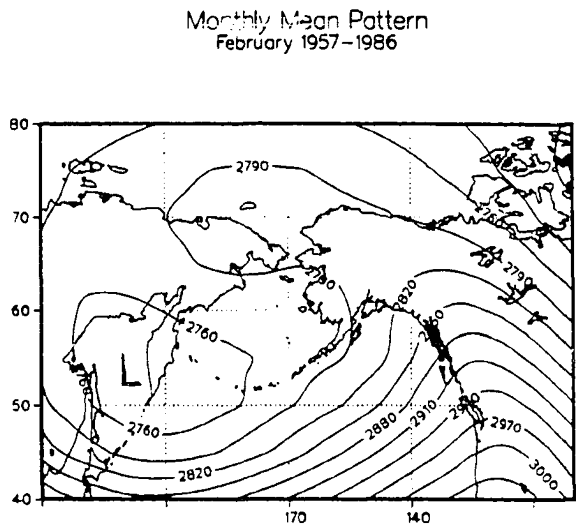




**Figure 5.18** February monthly average precipitation–South Coast Division 5 and thirty-year mean February $700mb$ circulation pattern. contours on map are $30m$; February 1979, the dry event, is circled in the precipitation plot.

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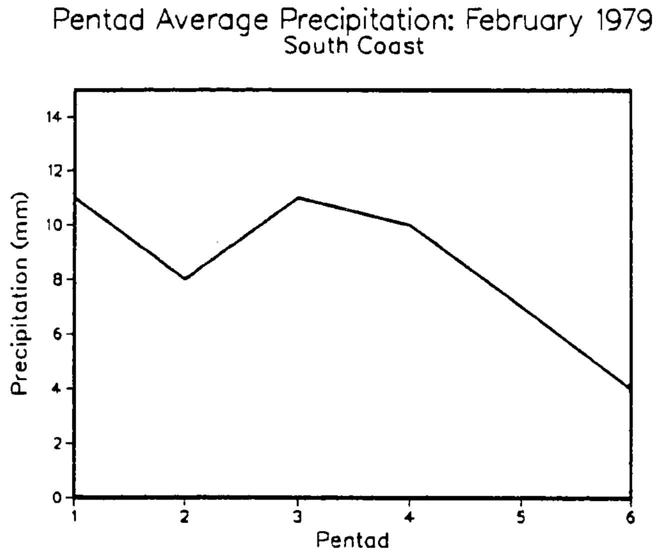


**Figure 5.19** February 1979 pentad (five-day) average precipitation. Copper River Division 4; pentad dates: 1= Jan. 29-Feb. 2, 2= Feb. 3-7, 3= Feb. 8-12, 4= Feb. 13-17, 5= Feb. 18-22, 6= Feb. 23-27.

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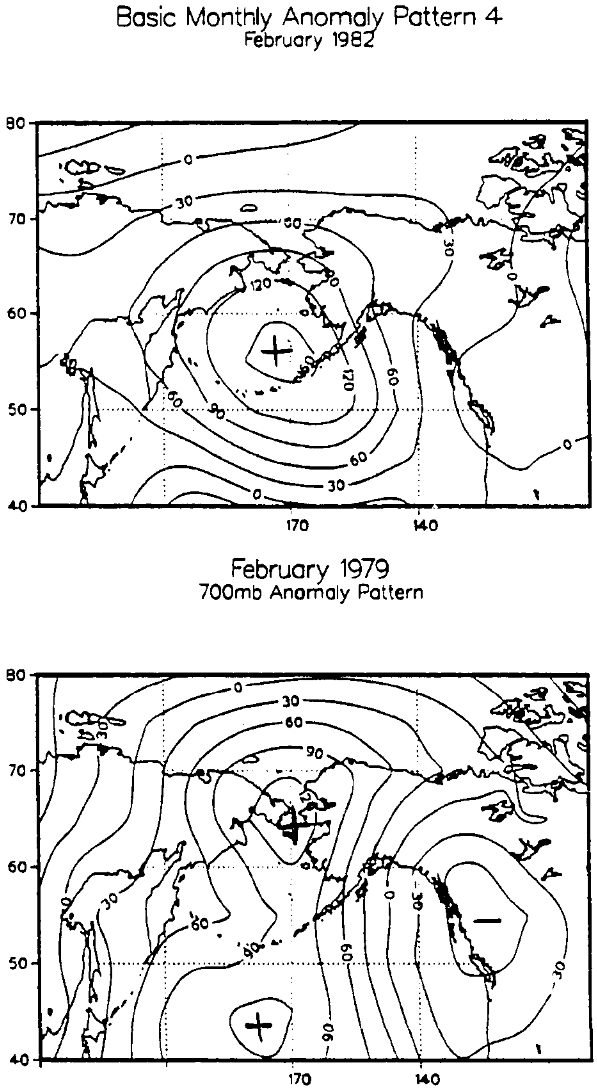


**Figure 5.20** Basic Anomaly Pattern 4 and February 1979 $700mb$ anomaly pattern. contours are $30m$ departures from the thirty-year mean.

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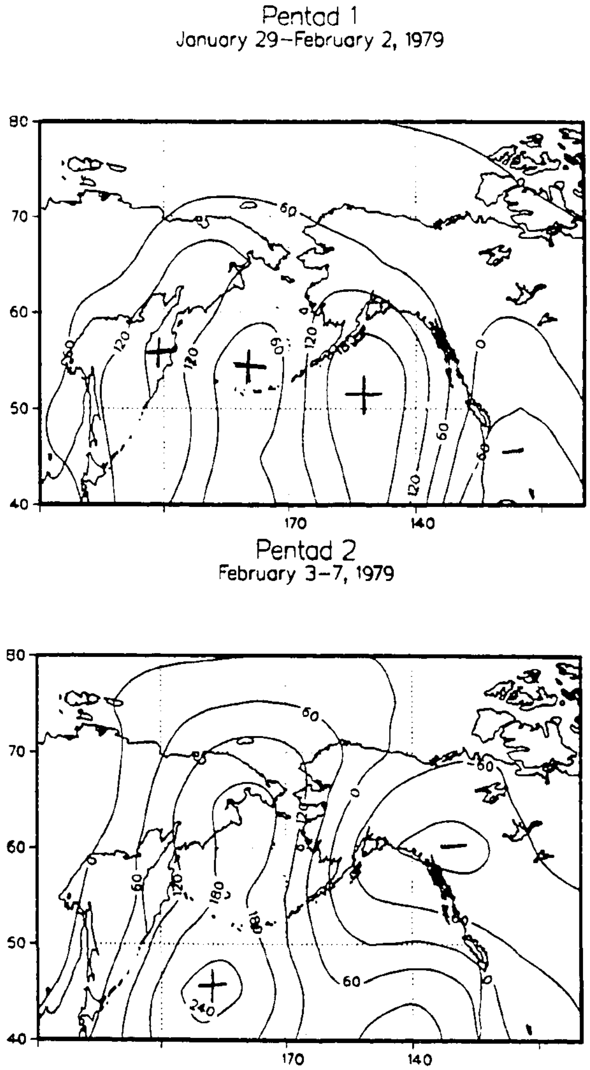


**Figure 5.21** 700*mb* anomaly maps for February 1979. Pentad 1 (P1) and Pentad 2 (P2); contours are 60*m* departures from the thirty-year pentad mean.

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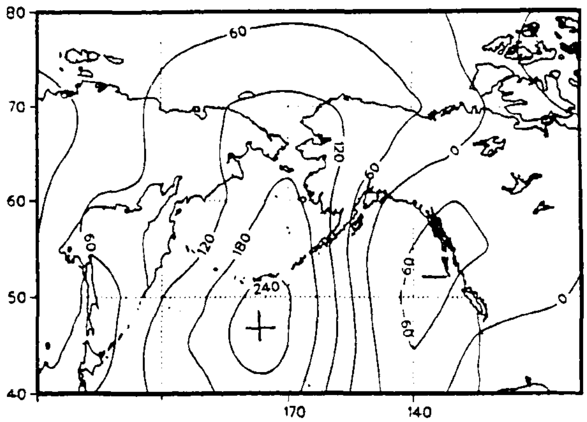
Pentad 3
February 8–12, 1979




Pentad 4
February 13–17, 1979

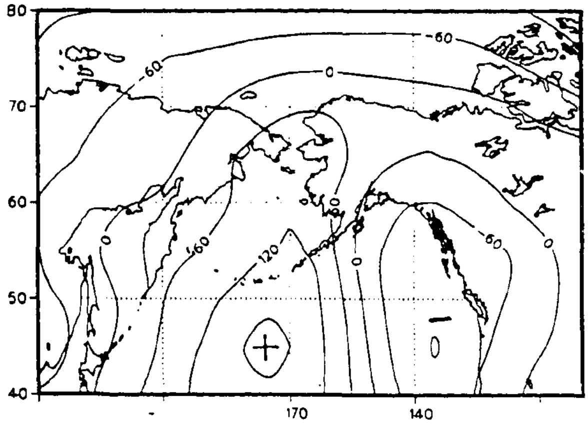



**Figure 5.21cont'd** 700*mb* anomaly maps for February 1979. Pentad 3 (P3) and Pentad 4 (P4); contours are 60*m* departures from the thirty-year pentad mean.

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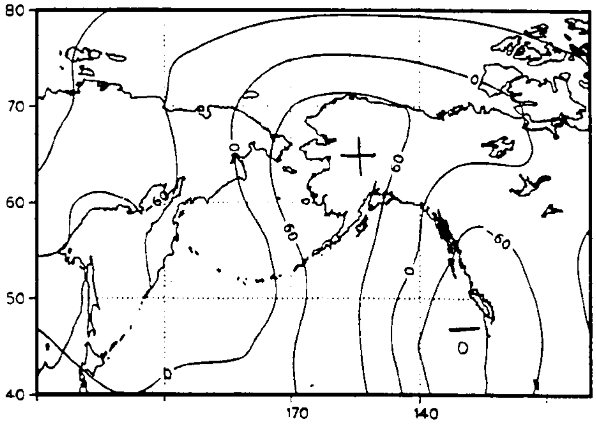
Pentad 5
February 18–22, 1979




Pentad 6
February 23–27, 1979

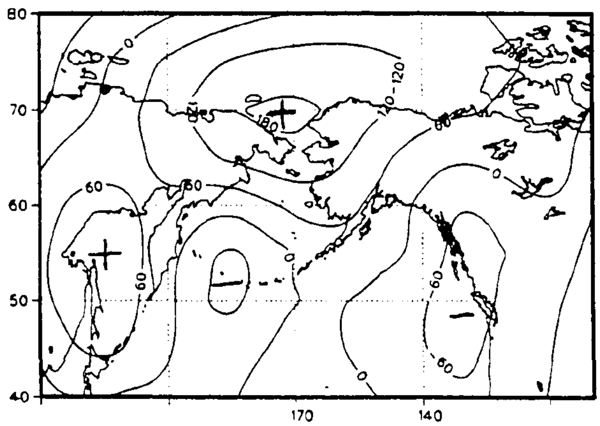



**Figure 5.21cont'd** 700*mb* anomaly maps for February 1979. Pentad 5 (P5) and Pentad 6 (P6); contours are 60*m* departures from the thirty-year pentad mean.

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of fluctuation evident in the precipitation values on this pentad scale. A periodicity of five days is suggested by the data depicted in Fig. 5.23. As was the case with the Southwestern Islands Division, the Bristol Bay Division climate also appears to be affected by the passage of large waves in the westerlies.

The thirty year mean December $700mb$ circulation (Fig. 5.22) is characterized by a trough over the Kamchatka Peninsula and a ridge along the west coast of Canada and southeastern Alaska. The pattern is "flat" over the Bristol Bay Division. December 1981 was classified as a Basic Anomaly Pattern 9 (BP9) month in Chapter 3. This basic pattern has mixed tendencies in the Bristol Bay Division (Table 5.4b). It can be associated with wet or dry climate conditions. The main feature on the basic anomaly chart (Fig. 5.24) is an area of below normal heights over Asia that extends to the Seward Peninsula of Alaska. A secondary area of negative height departures is found over the Gulf of Alaska. The positions of these features results in southwest and northeast flow into the Bristol Bay region. Pentad or five-day anomaly maps for December 1981 are shown in Fig. 5.25. P1 is characterized by a tongue of below normal heights extending southward from the Arctic across Siberia and western Alaska to the North Pacific. The largest departure is centered over Bristol Bay. P2 consists of large negative anomaly features over northern Asia and over the Gulf of Alaska. These features are separated by a positive anomaly of the same magnitude positioned over the Aleutian Islands. The dominant flow components into the Bristol Bay region are southwesterly, westerly, and northerly. P4 shows the Bristol Bay region under an area of negative height departures extending northwest from the Gulf of Alaska. The dominant flow direction associated with this feature is southeasterly. P5 shows a broad negative anomaly extending southeast from Eurasia to the Aleutian Islands. A secondary feature is an area of positive height departures located over the Gulf of Alaska. P5 suggests a more southerly/southwesterly flow tendency in the Bristol Bay Division. Pentads 3 and 6 were not used as the corresponding $700mb$ data was incomplete.

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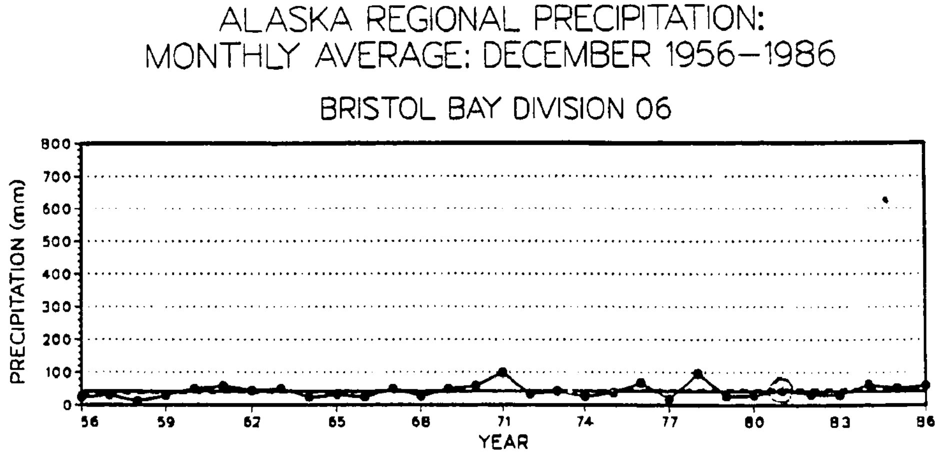
Normal Precipitation Event: December 1981



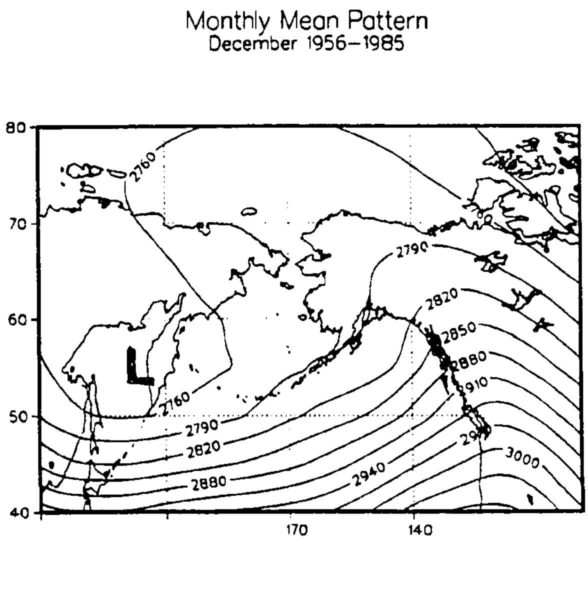




**Figure 5.22** December monthly average precipitation–Bristol Bay Division 6 and thirty-year mean December $700mb$ circulation pattern. contours on map are $30m$; December 1981, the normal event, is circled in the precipitation plot.

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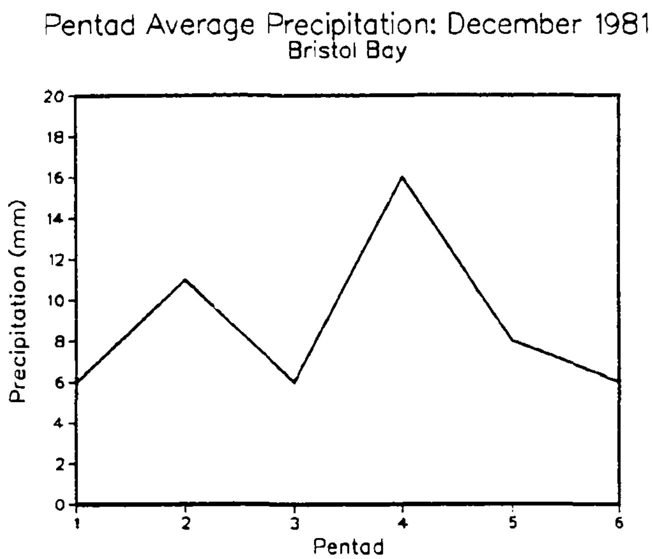


**Figure 5.23** December 1981 pentad (five-day) average precipitation. Bristol Bay Division 6; pentad dates: 1= Nov. 30-Dec. 4, 2= Dec. 5-9, 3= Dec. 10-14, 4= Dec. 15-19, 5= Dec. 20-24, 6= Dec. 25-29.

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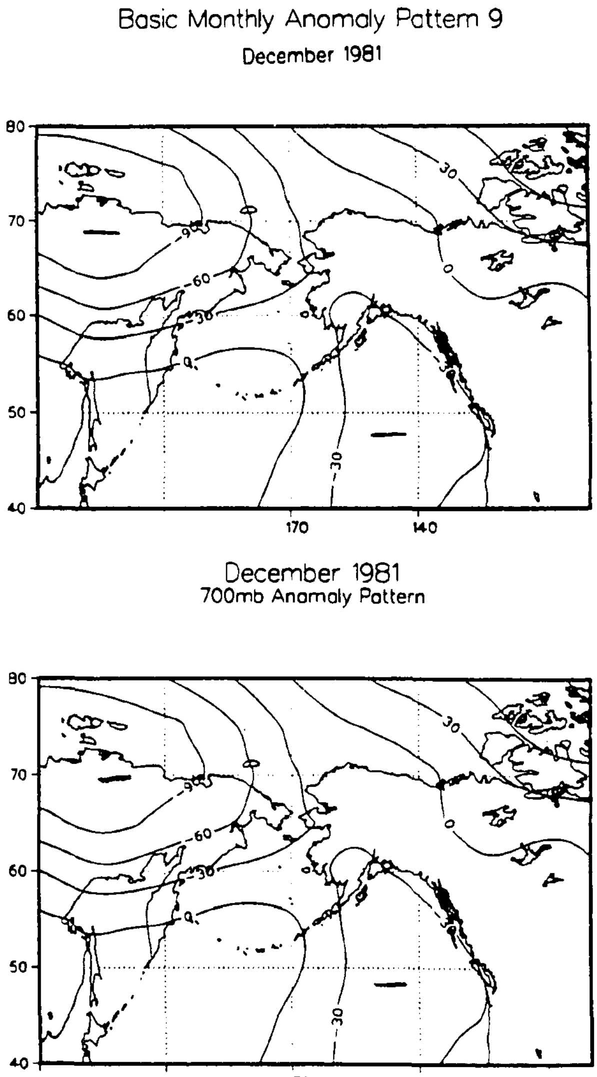


**Figure 5.24** Basic Anomaly Pattern 9 and December 1981 $700mb$ anomaly pattern. contours are $30m$ departures from the thirty-year mean.

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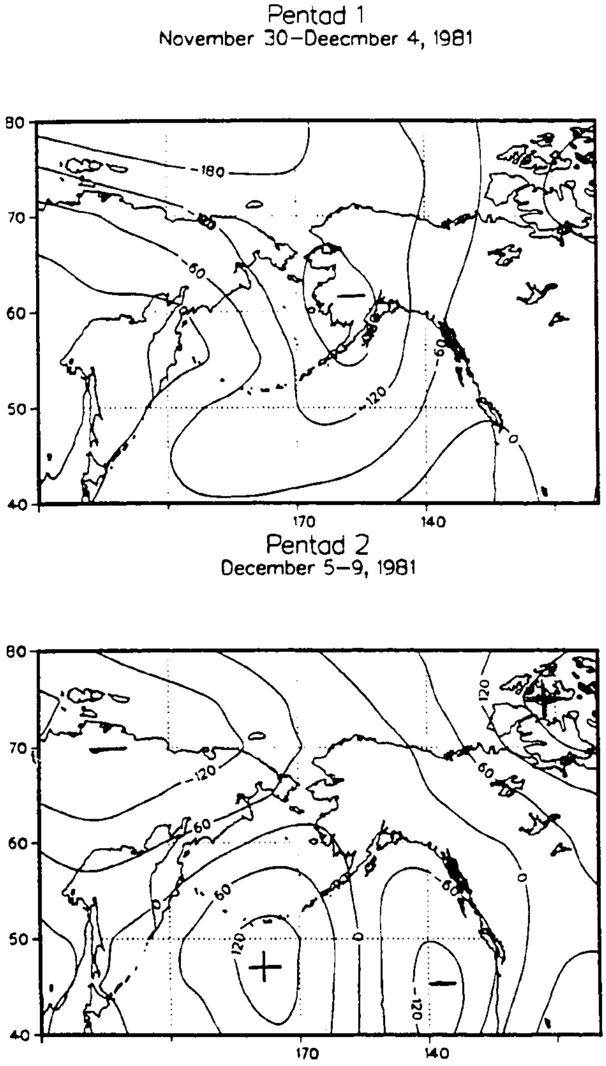


**Figure 5.25** 700$mb$ anomaly maps for December 1981. Pentad 1 (P1) and Pentad 2 (P2); contours are 60$m$ departures from the thirty-year pentad mean.

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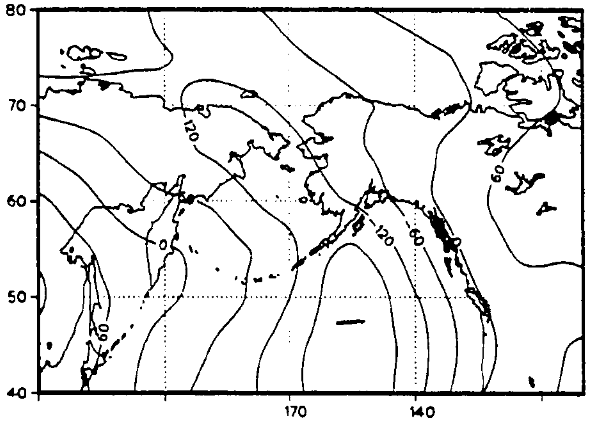
Pentad 4
December 15–19, 1981




Pentad 5
December 20–24, 1981

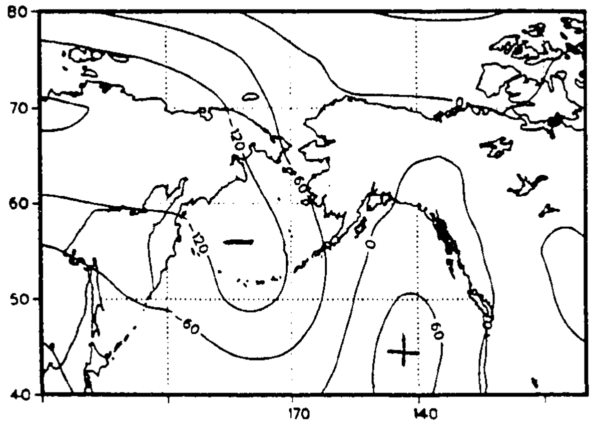



**Figure 5.25cont'd** $700mb$ anomaly maps for December 1981. Pentad 4 (P4) and Pentad 5 (P5); contours are $60m$ departures from the thirty-year pentad mean.

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In combining the circulation patterns and the precipitation data, a situation similar to the "normal" temperature event is apparent. The higher frequency phenomena are much more variable than the monthly- mean data would seem to indicate. The pentad charts (Figs. 5.25 and 5.23) suggest a five-day period of oscillation between dryer and wetter episodes. These variations have been effectively smoothed out during the monthly-mean calculation process. Using the pentad-scale charts as a basis for conclusion, it would appear that negative height departures existing over the Gulf of Alaska concurrently with positive height departures over the Aleutian Islands is a requirement for higher precipitation periods. This scenario allows the primarily ice-free Gulf of Alaska and the southern Bering Sea to act as source regions for $700mb$ moisture transport into the Bristol Bay Division.

### 5.5 Summary

Winter season monthly-mean temperatures seem to be strongly tied to the advective processes of heat transport. Monthly mean circulation anomalies describe temperature behavior quite well. Pentad anomalies further enforce the month-scale behavior. They also indicate the strength or persistence of temperature values.

Although exact lag/lead tendencies are still unclear, there does seem to be a notable connection between atmospheric circulation, monthly mean land-based temperatures and Gulf of Alaska sea surface temperatures. The cool period during the 1960's and 1970's appeared in both the sea surface temperature and the land-based temperature records. Douglas *et al.* (1982) found that the most prevalent $700mb$ circulation over the Gulf region during this period had a strengthened northerly flow component and/ or below normal heights. This fact was also noted in the division/pattern discussion earlier in this chapter.

Although the position of the individual $700mb$ anomalies and their resulting flow components appears to be important, it is the persistence of position that seems to be of most importance

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to temperature variability. Persistent monthly-scale northerly, northeasterly, or northwesterly flow resulted in much colder monthly-mean temperature values than did similarly directed pentad-scale flow.

Precipitation is not well described by the monthly mean scale; although, there are some indications that monthly mean Gulf of Alaska sea surface temperatures might influence the mean precipitation values. However, precipitation behavior is handled well at the pentad scale. The variations in precipitation seem to be tied to the position of anomaly features on the pentad charts of the six case studies examined. From this, it can be concluded that the precipitation characteristics of the climate divisions discussed here in the single events are more of a synoptic or individual storm-scale phenomenon.

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## Chapter 6: Concluding Remarks

Alaska's winter climatology has been described in terms of the associated $700mb$ geopotential height anomaly patterns and regional surface level temperature/ precipitation records. In doing so, the month-scale circulation anomaly patterns have been classified into ten representative basic categories which are distinctly different from each other. A total of 78% of the monthly anomaly maps from the winter seasons of 1956/57 to 1985/86 can be classified (correlation coefficient $> 0.60$) into these categories. Among the major features seen on the basic pattern charts are a positive anomaly or negative anomaly over the western Gulf of Alaska, a positive anomaly over Siberia and eastern Alaska, a negative anomaly over southeast Alaska, and a zero height departure zone over the Interior Division. These features do not all appear on the same chart, but they may appear in various combinations on more than one map. The basic patterns determined in Chapter 3 are similar to the patterns discussed in Chapter 2.

Regional climate has been described in terms of its temperature and precipitation variability over the same thirty year winter season period 1956/57 to 1985/86. The state was split into 10 geographic regions for this study. Nine were land-based and the tenth was the Gulf of Alaska. Monthly mean temperature and precipitation values were used. It was discovered that the most variability in terms of precipitation occurred in the regions closest to the Gulf of Alaska, the Southeastern Division, the South Coast Division, and Cook Inlet. The least amount of variability in precipitation occurred in the Interior Basin Division and the Arctic Drainage. The most variable temperatures occurred in the Interior Basin Division, Arctic Drainage Division, and the West Central Division. It was also noted that there appears to be a connection between the Gulf of Alaska sea surface temperatures and the precipitation variability in the coastal station, as well as the temperature variability throughout the state. One of the most prominent periods of anomalous climate behavior was the January period



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from 1964- 1977 where all ten divisions showed below normal temperatures and most divisions were also dryer than normal. The period preceeding this episode was warm and the period after was extremely variable on the interannual scale. This appears to coincide with the concept of a low frequency oscillation between warm and cold episodes as suggested by Bowling (pers. comm.) and Royer (1989). Most of the extreme anomalies in terms of both temperature and precipitation occurred from the mid-1970's to the end of the study period.

On a seasonal-scale, it was shown that the coldest winters throughout the state occurred during the period from 1968 to 1975. The winter seasons that followed the cold period were more variable and in several cases, warmer than the winter seasons preceding the cold period. A *linear* (least squares) fit to the thirty-year (1956/86) time series of winter season average temperatures indicates a significant (90% C.I. level) warming trend in the Interior Basin Division, and a large warming trend in the Bristol Bay Division.

Seasonal precipitation averages were quite variable throughout the state, and from season to season. A *linear* approximation to each divisions' winter season average precipitation time series indicated a significant trend (90% C.I. level) in the Southwestern Islands Division (increasing) and in the Copper River Division (large decrease).

When the atmospheric anomalies were combined with the surface climate, associations between certain types of climatic behavior and certain circulation patterns were evident. This was noted on both the state and regional level. Patterns could be defined according to most prevalent climatic states in a region as the patterns tended to exist during specific weather. Certain warm and/or wet patterns were not present during the cold January period and they were present previously and after. Patterns with local northwesterly/ northerly and in some cases, westerly flow components occurred concurrently with cool SST and also cool air temperatures.

It was also noted in case studies of representative extreme events that precipitation is more of a synoptic or single-storm phenomenon. Precipitation is not well described by the corresponding

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concurrent monthly-scale anomaly pattern, but it is handled well with pentad scale circulation. Temperature variations are indicated well by the monthly anomaly patterns.

This thesis research is meant to serve as a foundation for future Alaska climate research. It has updated what is currently known about the winter system, and provided new information on the interactions between atmospheric circulation, surface climatology, and sea surface temperature. As it is an objective synoptic climatology, the results are suitable for use as basic input for a regional climate model of Alaska's winter variability.

There is much more work yet to be accomplished in terms of Alaska climate and its role in the Arctic system. The synoptic climatology needs to be expanded to include the entire year. Other climate elements such as wind and cloud cover need to be incorporated into the surface climatology section. Perhaps a more in-depth look at the variability of one region or within in region would be profitable. The correlations between surface air temperature and sea surface temperature need to be examined in more detail to determine the proper lag/lead behavior, especially in terms of longer-scale (and shorter-scale) events and global forcing. This is vital to the concept of air-land-sea-ice feedback loops. Although this month-scale synoptic climatology is quite informative in terms of what has happened and what is happening, the scale of the entire system synoptic climatology will eventually need to be reduced to a higher-frequency (i.e. 5-10 day) scale for shorter-term prediction purposes.

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